AN ELECTROMYOGRAPHICAL STUDY OF THE LABIAL MUSCLES IN SPEECH, WITH SPECIAL REFERENCE TO THE VOWELS OF THAI

A Thesis submitted to the University of London
for the Degree of Doctor of Philosophy

by

Anchalee Pasuknirant

School of Oriental and African Studies

ABSTRACT

The study was based on electromyographic investigation techniques. Surface bipolar paint-on electrode type was employed. Data analysis was manually manipulated. The muscles undergoing investigation were those of the lip muscles: orbicularis oris inferioris, depressor labii inferioris and mentalis. Muscular activation of each muscle was studied in terms of two dimensions: time dimension and intensity dimension. Time dimension (in msec.) was divided into two categories: time-onset and time-duration. Intensity was studied by comparing temporal difference of averaged integrated curves of vowel production of the same muscle. Muscular activation of the three muscles was also studied from the point of view of time-coordination; that is to say the sequence of activation of the muscles in the production of a specific vowel over a period of time.

The results of the investigation are discussed in terms of the roles of the three muscles in the articulatory aspects of the vowels. Also discussions in relation to traditional views of the universality of the syllable structure CV, the treatment of rounding, tense/lax in the distinctive feature model of phonology are presented.

ACKNOWLEDGEMENTS

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CHAPTER 1

ORIENTATION OF ELECTROMYOGRAPHY

Electromyography is a new technique in neurophysiology. The technique that deals with electrical potentials produced by muscle upon its contraction, was launched almost fifty years ago by English and American physiologists (Adrian and Bronk; Denny-Brown) and several Scandinavians. However, these men and their colleages did not concern themselves with the use of the new techniques for unravelling the functions of individual muscles and groups of muscles. It must be admitted that the earliest techniques were really not appropriate for such detailed studies. When electromyography was later applied to man it was more for diagnostic and clinical reasons than for basic kinesiology.

Historically, at the end of the eighteenth century, in 1792, Galvani, a French physicist, discovered that skeletal muscles will contract when stimulated electrically and conversely, they produce electrical discharge when they contract from any cause. He believed that muscles stored and discharged electricity received from the nerves.

It was not until in the late sixties that electromyography was introduced into the area of experimental phonetics. The Haskins laboratory experimentalists; Cooper, Liberman, Harris and Grubb (1958) attempted to show correlations between electromyographic signals and phonemic units. They presented their paper in the II International Congress of Cybernetics, Namur, Belgium in September, 1958. In 1961, the first electromyographic study of the lips appeared on the topic

"Electromyography as a speech research techniques with an application to labial stops" by Saught et al. Following that, in 1962, 1965 Harris et al. presented electromyographic studies on lip muscle on the topics "Component gestures in the production of oral and nasal labial stops" and "Some aspects of the production of oral and nasal labial stops", respectively. Later, in 1966, Fromkin reported her widely cited electromyographic investigation on the title "Neuro-muscular Specification of Linguistic Units". After then Phonetics reports under electromyographic investigation techniques have been continuously carried out, mostly by American, English and Swedish scholars.

The basis of electromyography.

The motor unit. The unit consists of a single motoneurone. Its important functional parts are the cell body, nucleus, the dendrites attached to the body, and the axon with its various branches or axon collaterals (see Fig I). The axon collaterals terminate either on, other neurones or on muscle fibres at regions known as end-plates. The axon is usually referred to as the nerve fibre. Dendrites are nerve processes conducting the neural impulse towards the nucleus, whereas the axons normally conduct the neural impulse away from the nucleus (see Fig II). Functionally, a single muscle cannot contract as an individual, instead individual motor units are the smallest functional elecments. The number of muscle fibres served by an axon varies widely. Generally, it has been agreed that muscles controlling fine movements and adjustments (such as those attached to the eyeball, and the larynx) have the smallest number of muscle fibres per motor unit. On the other hand, large unsophisticated-acting muscles, for example, those in the limbs, consist of motor units, with a correspondingly large number of muscle fibres.

The neural impulses which are in the form of action-potential "spikes" descend the axon as a series of pulses (Hodgkin, 1964). The size of the stimulus is not reflected in the size of the action-potential but in the frequency of the spikes. The greater the stimulus the higher the frequency of spikes (Hardcastle, 1976). Generally, the action potentials picked up are the electrical discharge of several motor units within a muscle, hence the term "Electromyographic (EMG) potential" is also in general use.

Motor Unit Recruitment. The normal pattern of recruitment is that under normal conditions, the smaller potentials appear first with a slight contraction and as the force is increased larger and larger potentials are recruited, and all motor units increase their frequency of firing (Henneman et al, 1965; Olsen et al, 1968; Grimby and Hannerz, 1968, 1970). Accordingly, in the muscular activity of speech there are generally two patterns of EMG action-potentials. Leanderson and Lindblom (1972) gave the terms: prespeech or background and articulatory activities. The phenomena of the speech musculature of a prespeech activity are indicated slight muscular contractions occurring while a subject assumes a preparatory speech posture of the lips. Articulatory activity phenomena are associated with the first element of the utterance involving the labial activity. the latter activity is revealed by vigorous EMG action potentials (see Fig. III).

Moreover, MacNielage (1974:1) explained that some motor units in speech musculature may have a double range of firing: a Primary range of firing at lower rates during constant contraction levels, and a Secondary range of firing at high rates during rapid increases in contraction. As force increases are made to increase firing frequencies other units are recruited. According to MacNielage (1974:5) the action potential size is not necessarily related to the motor unit size as suggested by Kernell (1965; 1966), by Öhman (1965). According to Kernell and Öhman' suggestion, the natural range of firing frequencies of a motoneuron depends in a simple way on its size. Large nerve fibers have higher firing frequencies than smaller fibers. MacNielage (1974) suggested that it is highly dependent on the distance of the unit from the electrode. Granit (1970. 1972) gave other evidenc contrary to the size principle that there are relatively separate functional systems controlling motoneurons, a tonic and a phasic system. The tonic system is associated with control of continuous firing; the phasic system is associated with rapid contraction charges.

Besides, it was discovered that man can be trained to suppress the small, low-threshhold units. That is, subject with biofeedback assistance could reverse the recruitment order of motor units from the normal pattern (Basmajian, 1965; Basmajian et al 1965; Ashworth, Grimby and Kugelberg 1967). Importantly, an electromyographic study of normal speakers can provide a preliminary baseline for clinical applications and the further study of articulatory disorders.

Type of Electrodes. Generally the electrodes used in electromyography are divided into two categories: inserted electrodes, and surface electrodes. However, according to their physical appearance there are sub-varieties in each group, see Basmajian (1974: 27-38).

The advantages of the inserted electrodes technique are:

1. An investigator can obtain access to the nearest location of motor units of the muscle under investigation provided the technique is under the control of an expert physiologist.
2. The technique usually provides clear and sharp spikes.
3. It does not yield broad pick-up caused by the influence of the neighbouring muscles.

Disadvantages of the inserted electrodes technique:

1. Besides the pain normally expected, it is possible, though rare, to get infection, brain damage, or haematoma (Kahn, 1973).
2. There is the problem of sterilization. Since a thoroughly hygienic treatment is required, the needle must be left in alcohol for several hours, after that auto-claving and dry heat are needed. The matter is even more complicated for the inserted fine-wire electrodes, as a special sterilization treatment is necessary to be attained in order to avoid condensation of moisture as well as melting off the nylon insulation (Basmajian 1974: 31).

The surface electrodes technique, that once was neglected because of unsatisfactory results, is at present returning to favour in speech research. This is partly the result of the recently modified technique using surface bipolar paint-on electrodes which was employed in this study. The technique was developed by Hollis and Harrison (1970), and also Allen, Lubker, and Harrison (1972). The paint is a mixture of glue, acetone and fine silver flakes. To be able to apply this semi-liquid mosture in a uniform shape, a plastic template in which two small holes were made was included among the electronic apparatus.

Advantages of the surface electrodes technique:

1. There is convenience both in preparation and application.

2. The technique gives less discomfort as well as offering no risk to the subject.

3. The technique is useful in crude or generalized studies, or studies in which the out put of a whole large area or group of muscles is desired.

Disadvantages of the surface electrodes:

1. For the traditional surface electrodes there are defects of electrical insulation between the skin and the electrodes.

2. The electrodes may pick up too broadly unless care is taken concerning the muscle location. In spite, many of the results obtained could be deduced with reasonable care from palpation and direct inspection of the muscles in action.

In short,though the electrodes employed in electromyography actually are of a wide variety of types and constructions, their use depends on the fundamental principle. That is, they must be relatively harmless and must be brought close enough to the muscle under investigation to pick up its electrical discharges.

Purpose and scope of the study.

In terms of modern articulatory phonetics "speech" is recognised as "...a dynamic process involving many coordinated articulatory processes rather than as a sequence of relatively static postures involving one of two of the articualtor organs" (Henderson, 1965: 16). At the present time, electromyography offers one possible way of getting at the physiological basis for phonological units. In other words, it is the study of the correlations between linguistic units and the motor commands into which they are encoded at the articulatory level in the brain. As Hirose (1971; 73) said of the use of electromyographic technique "...it can provide information about the speech gesture in its natural units and...it directly reflects the motor command from the central nervous system carried by neural impulses. Recent technical developments in Electromyography have made possible examination of the articulatory muscles without affecting natural speech performance."

The aim of the investigation specifically was to study the features of labial muscular activity involved in the production of rounded, spread, and neutral vowels and to compare the intensity pattern of specific muscles in rounding, spreading, and neutral postures. It must be also stated here that across subject study was avoided due to the risk of high variability.

In the aspect of comparative study, two hypothesis were tested The first hypothesis tested was that the lip muscles would display non-activity for the neutral vowels. The second hypothesis had to do with the correlation between long, short;tense, lax that is the muscles under study would display a greater intensity pattern for the production of long vowels than for short counterparts.

The results from this study would be a constructive guideline not only to the linguistic description of Thai but also to the area of teaching Thai pronunciation as well as to clinical research of speech.

The study was concentrated on the activity of the three major lip muscles: the orbicularis oris inferioris, the depressor labii inferioris, and the mentalis. The data were made available by the technique of electromyography. The investigation was carried out in the Physiological and Speech Lab., Linguistics Institute, Stockholm University, under the supervision of Dr. James Lubker, Dr. Robert McAllister, and Mr. Jan Carlson, during 1976.

Variability.

One important event inevitably occurs in electromyographic investigation is variability of the EMG patterns associated with utterances which are acoustically similar. According to Leanderson and Lindblom (1972), each normal speaker appeared to have a characteristic electromyographic pattern comprising background and articulatory activity; the reproducibility of this pattern was good for the same utterance in the same subject.

Possible sources of variability should be mentioned here:
Firstly, psychological condition of subjects is a crucial point for any EMG experimentalist to be aware of. Naturally as a chain reaction, psychological condition has effects on chemical reaction in muscle tissues from which electrical discharge is picked up by electromyography device. Thus, subjects in relaxing nature are to be chosen than those in tense or temperamental mood.
Secondly, muscle location is also important in the case that the experiment is carried on more than one period of time. Once the electrodes are removed out from the muscle it is indeed very difficult to re-establish the electrodes in the same position and location in order to carry on the same experiment.
Thirdly, in the case of manual analysis measurement procedures must be confirmly decided. High variation may occur if base-line, onset phase and offset phase of the electrical potentials have not been thoroughly and definitely decided. In the case of computer analysis lack of visual monitoring will certainly cause high variability because artifacts which normally occur will be included.
Fourthly, considerable number of utterances used as variability indicator, A few utterances cannot provide satisfied data because it does not indicate whether the performance is constant or variant.

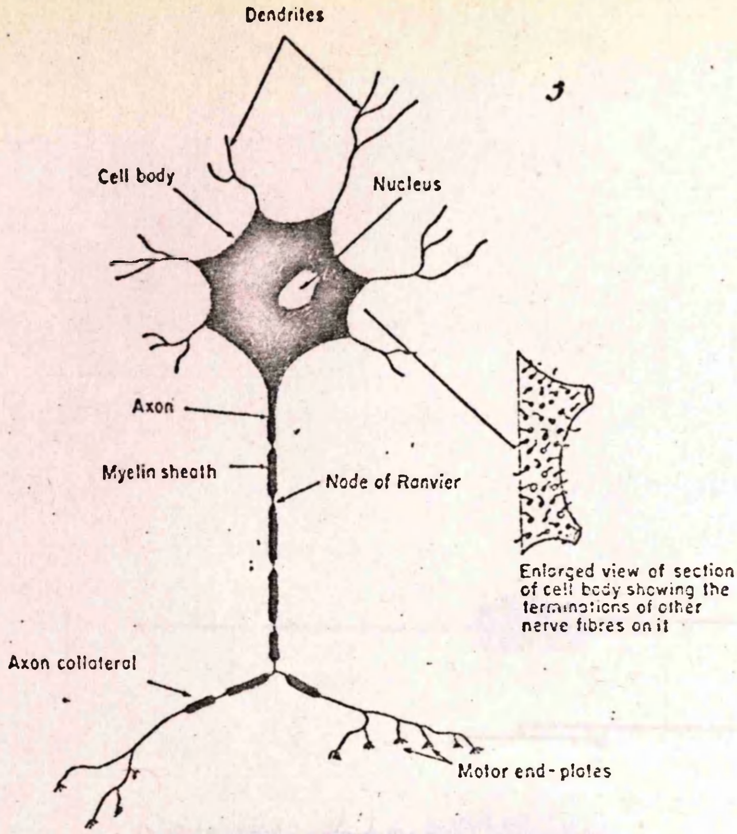


Fig. I A diagram of a nerve cell and impulse circulation.
(after Cunningham, 1972: 587)

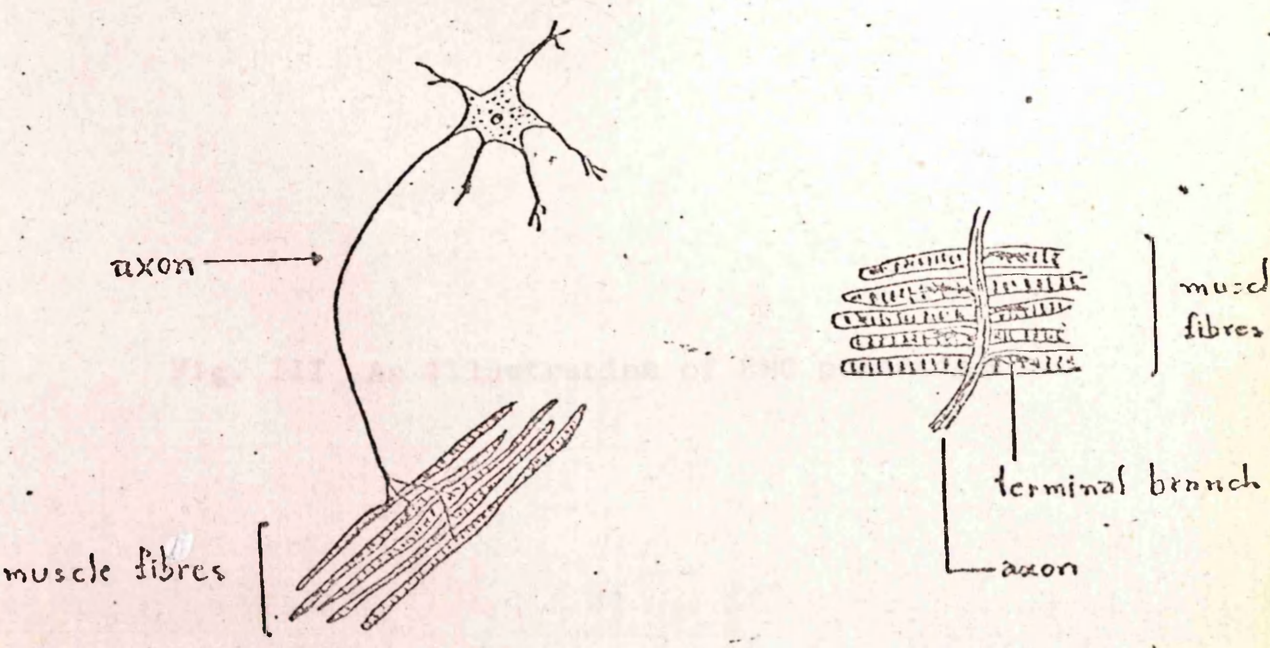


Fig. II Diagrams of a motor unit.

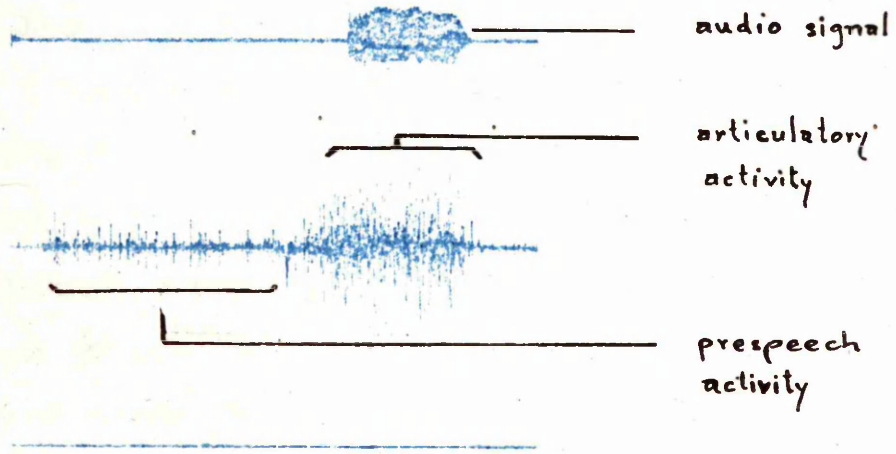


Fig. III An illustration of EMG potentials.

CHAPTER 2

LITERATURE REVIEW
&
PRESENT WORK DATA COLLECTING PROCEDURES

Electromyography in speech production research has been quite an interesting aspect of experimental phonetics for more than two decades. In this chapter data presentation and measurement technique demonstrated in EMG research papers are examined.

One of many interesting papers is " Neuro-muscular specification of linguistic units " by Fromkin (1966). In this paper only activity of the orbicularis oris inferioris was investigated. Surface electrode, suction type, was placed at the medial line of the lower lip on the vermilion border. Data presentation was made in the form of integrated curves. Measurements through computure analysis procedure were made on the following points:

(A) Peak amplitude

(B) Duration of muscle action

(C) Onset of muscle action to audio onset

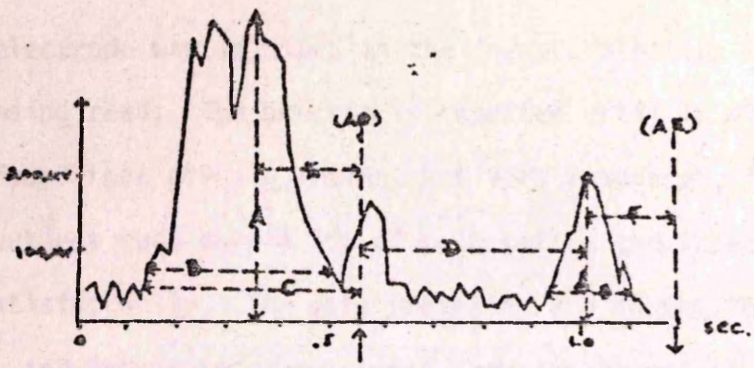
(D) Audio onset to onset of muscle action

(E) Peak amplitude to audio onset

(F) Peak amplitude to end of audio

(AO) Audio onset

(AE) End of audio signals

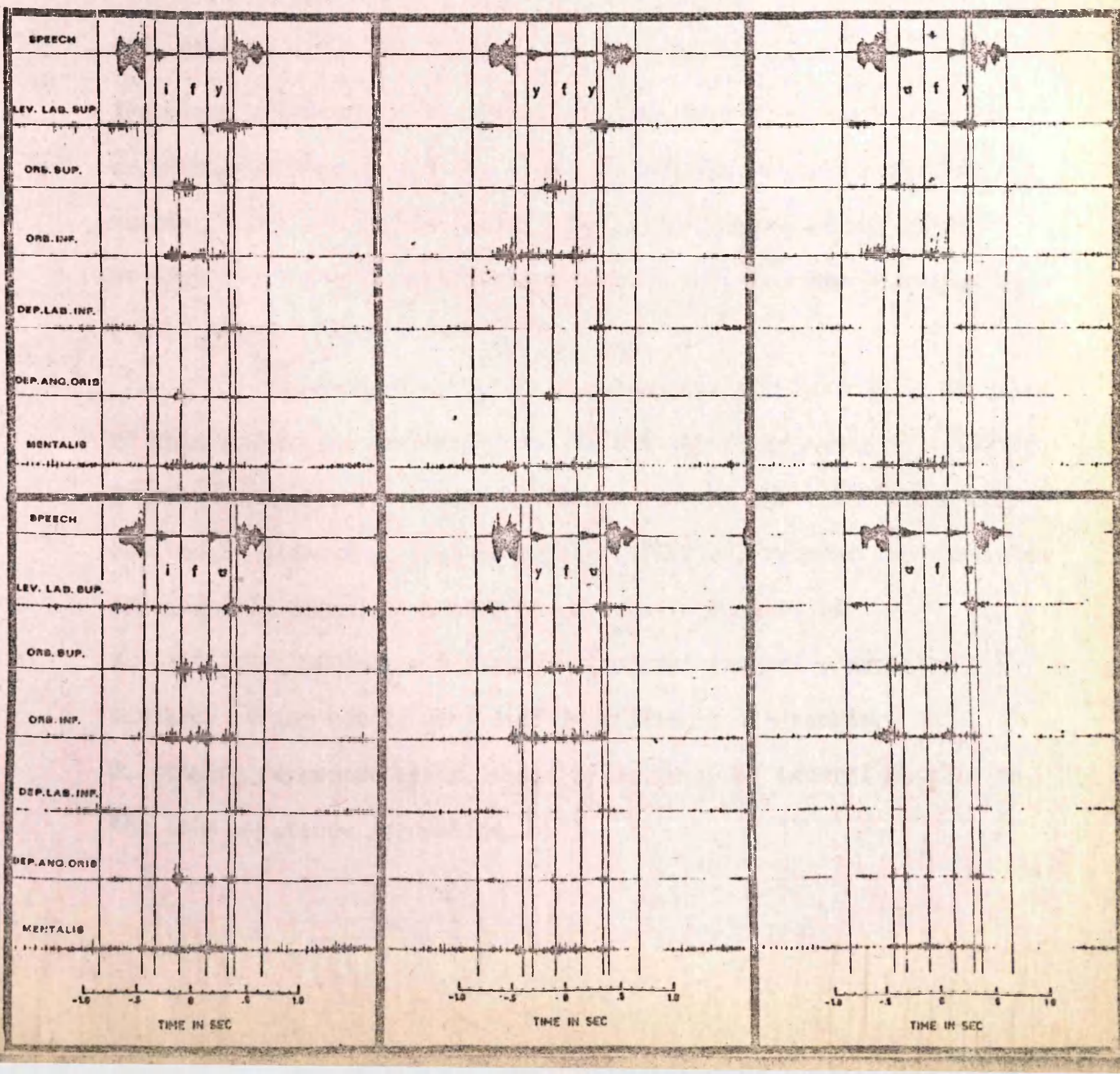


Fromkin's Measurement Model.

As the matter of fact Fromkin' model is rather unrealistic. For example, on the amplitude dimension there are usually more than one form of high peaks. Thus, establishing the accurate highest point is in fact the real problem. Besides, along the time dimension there is no criteria to set up precisely the beginning of the onset and cessation of muscular activity.

A similar EMG paper to that of Fromkin, however with sophisticated technique, was also presented by Tatham and Morton (1967) " Some Electromyography Data Towards a Model of Sppech Production". That is surface electrode suction type was used on the orbicularis oris superioris, and the measurements were made on EMG integrated curves along the amplitude and the time dimensions. Nevertheless, the measurement on duration parameter was established from the point where the integrated signal rose above the noise level to where it fell below the same level.

Another well known paper on EMG is "Peripheral Motor Commands in Labial Articulation" by Öhman (1968). The data presented in the paper were collected by investigating the speech activity of the facial muscles of a male Swedish speaker. The muscular activity of: levator labii superioris, orbicularis oris superioris, orbicularis oris inferioris, depressor labii inferioris, mentalis, risorius, depressor anguli, was recorded with needle electrodes. According to the electrode insertion technique given in the paper "... the electrode was adjusted in the in/out direction while the list was being read. The process is repeated until an electróde depth is found that gives a maximal activity response", it seems that the subject must bare a lot of pain before the insertion was located satisfactorily. The data presented are in the forms of raw EMG trace, and integrated curve taken from the amount of activity of five repeated readings. Mainly, the raw EMG potentials were displayed with the audio signals confined by the time scale. However, there is no specific measurement procedure introduced. Nevertheless, it may be misleading when all the raw EMG potentials of the muscles investigated were displayed in the same chart as the following sample.



In addition in the final conclusion part, there is a table of comparison of the relative degrees of excitation of the labial muscles studied during articulation of the three vowels i , y , u , as quoted below:

	i	y	u
lev. lab. sup.	+	(+)	-
orb. sup	0	0	+
orb. inf.	0	+	(+)
dep. lab. inf.	+	-	-
mentalis	0	+	(+)
risorius	+	0	0
dep. ang.	0	0	+

The minus sign represents inhibition, the zero sign unaffectedness or unknown activity, and the plus sign excitation. If a certain muscle is excited in two vowels, the lesser degree of excitation is signified by a plus within parentreses and the greater degree by a plus without parentheses.

Accordingly, any one who examines the table must be aware of this comparison presentation. In the aspect of muscular activity comparison study, it is save to take a look at the table along the horizontal dimension. Due to physiological differences among muscles and probably technical artifacts one should compare on:

1. intensity parameter basis, the temparal intensity muscular activity of one muscle activated in different utterances.
2. timing parameter basis, muscular activity of several muscles in the same utterance production.

Another interesting EMG research paper on speech is " Facial muscle activity in the production of Swedish vowels: an electromyographic study" by Hadding, Hirose and Harris (1976). In this investigation needle electrode, hooked-wire type, was applied to; orbicularis oris superioris, orbicularis oris inferioris, orbicularis oris at the angle of mouth, buccinator, depressor labii inferioris, depressor anguli oris, mentalis, anterior belly of the digastric. The experiment was repeated three times within a 6-week period which means that there might be differences concerning muscle placement. Thus, there was great variation occurred between the runs. Apparently, data presentations were in the form of EMG integrated curves revealing muscular intensity patterns underlined by appoximate duration bars in msec. scale. There was no presentation of raw EMG trace.

Another EMG research on speech " Muscle activation for labial speech gestures" by Leanderson and Lindblom is to be mentioned here. That is, it was stated that the study involved 10 adult subjects and all measurements were made by the same investigator. The S.E.M. (standard errors of means) was also employed. The study was concentrated on timing parameter. Thus, raw EMG traces of muscles investigated were displayed in order to compare duration of muscular activity of one utterance. However, the raw EMG traces of only one subject were presented in spite of 10 subjects were used. It would be probably worthwhile to display variability among the subjects.

Above all, Lubker, AcAllister and Carlson of Stockholm University research group presented more elaborated data analysis procedure (1974, 1975) which was used in this present investigation of Thai.

Anatomy and physiology of the labial muscles under investigation.

Functionally and physically, there are three kinds of muscle structures found in our bodies, namely: cardiac muscle (heart muscle), smooth muscle (muscle of internal organs and blood vessels) and striated muscle. Both the cardiac and the smooth muscles work independently and automatically; they are controlled by the innervation of the involuntary neurological system, therefore, "involuntary muscle" is another name applied to them. By contrast, striated muscle is to be controlled by the voluntary neurological system. Since most striated muscles are attached to the skeleton, the name "skeletal muscle", as well as the term "voluntary muscle", is assigned to this group. The muscles to be investigated through electromyographic techniques in the present studies are those of the voluntary group. The facial muscles, which are also classified into the voluntary group, are innervated by the cranial nerve no. VII.

The muscles investigated here actually are parts of the facial muscles. Most of the facial muscles, however, act directly upon the lips, which affect the mobile part of the face. Changes in the shape of the lips also have an impact on oral resonance. The labial muscles are of the voluntary, striated type, made up of bundles containing long cylindrical fibres that run parallel.

Muscle selection. In fact the speech musculature can be physiologically classified into three main groups; respiratory, laryngeal, and articulatory. By location and function the lip muscles are included inthe articulatory group. Since the lower lip is generally more active than the upper part (Lubker, et al. 1974; Hadding, 1976) the investigation was concentrated upon the muscles of the lower lip. The muscles of the lower lip that underwent the investigation were the orbicularis oris inferioris (OOI), the depressor labii inferioris (DLI), and the mentalis (Ment.). Selection of those muscles was based on the following criteria:

Firstly, the EMG investigation of labial muscles has never been made on Thai before.

Secondly, due to the employed technique, surface electrode type is efficiently applicable to surface muscle.

Thirdly, their size and location are easily accessible.

Additionally, according to Dr. Lubker's supervision the activity of those three surface muscles for vowel production are interesting to study.

The OOI muscle is of sphincter type, forming an oval ring encircling the mouth. It is composed of a series of muscle bundles which insert radically into the oris bundle from various directions (Zemlin, 1964: 235). The orbicularis oris muscle functions as the compressor, contractor and protruder of the lips.

The DLI muscle is large, flat and of quadrangular shape, hence, it is also known by the name: quadrangular labii inferioris. The origin of this muscle is on the outer surface of the mandible. It travels upward and medially between the symphysis and the mental foramen. The muscle draws the lower lip downward and slightly lateralward.

The mentalis muscle varies in size from individual to individual. The muscle originates in the incisivefossa of the mandible, though having a deep origin it has superficial insertion to reach the OOI on one end; and it travels medially and downward to insert in the integument of the chin on the other end. It appears that the action of the mentalis muscle is to raise and wrinkle the chin. According to the Kennedy and Abb's report (1975) and Öhman, et al. (1966) it also contracts antagonistically to the DLI. In addition, it aids in protruding and turning the lower lip upward as in the expression of doubt (Kaplan, 1960).

Electrode placement procedure.

Among the muscles investigated the location of the orbicularis oris muscle is the most accessible. Th e muscle has also been found to be the most consistent of the perioral system in terms of size, fibre development and location (Kennedy and Abbs, 1975: 22). Based on the placement suggestions of Isley and Basmajian (1973), Sussman (1973), Kennedy and Abbs (1975: 35-38), the paint was applied to the lower lip at the vermilion border on the left side of the medial line. The sites of the muscles were cleaned by alcohol before the application of the paint, in order to reduce impedence.

In the case of the DLI muscle, a more restricted site must be located to avoid the fibre-blending of the inferior portion of the OOI muscle. The location suggested by Kennedy and Abbs (1975) was used for this muscle as well. The placement suggested was 15 mm. horizontally to the angle of the mouth, and vertically one-half the distance from the level of the apposition of the lips to the inferior border of the chin.

The placement of the mentalis muscle was chosen by protruding the lower lip. It is quite obvious that upon the contraction of the mentalis muscle the surface of the chin becomes wrinkled. Then the paint was put on in the area of the medial line where the contraction had been noticed. After the sites of the muscles were decided and the cleansing was done, the template was pressed on with the holes over the located sites. Then the mixture was applied through the holes, the two silver uniform spots appearing on the skin after lifting the template away. Fine-wires (Karma alloy 0.05 mm diameter) which were cut and prepared beforehand were then laid across the spots. To secure the wires in place as well as to establish electrical contact, a second drop was then applied to each spot. The other ends of the wires were clipped by gold (the material proved to be the best electrical conductor) coated springs which are attached to a rack mounted on a pair of eye-glass frames. From this rack an earth line was clipped to the subject's ear,(see Fig. IX-X).

The subject was seated in front of a microphone (Sennheiser MD 421) in a room shielded from electrical and magnetic interference. The utterances were read out from the cards one by one in the subject's normal speech style which is classified by the subject as relatively slow. The readings were repeated five times.

The electrical discharges from the muscles were picked up by the electrodes, then passed through the gold-coated springs from which the signals were transmitted to the EMG amplifiers (Fornema), then through the cathode-ray oscillograph screen. After that they were recorded on a 4-track tape recorder (TEAC A-3340) simultaneously with the acoustic signal. From the recorder the raw electromyographic signal was to pass through an integrator at 25 mm., inorder to obtain a total out-look of the raw EMG signal; the out-put from the integrator was called the integrated electromyographic curve. Then, the raw electromyographic signal, (henceforth called EMG) the integrated electromyographic curve (henceforth called IC). and the acoustic signal (henceforth called AS), were written out on paper by the mingograph (Siemens 34 T ink-writer) at of 100 msec. For the sake of clarity the raw EMG, the integrated curve and the acoustic signal were transferred to paper for one muscle at a time. (see Fig.XIfor the diagrams).

Measurement procedure.

As Mansell (1974) described that EMG signals have certain more-or-less define time characteristics at least a single peak. Unfortunatly, a single peak never appeared in the data of the present investigation. The measurement of the present work was concentrated on two basic dimensions. One is along the time dimension concerning: the time-onset of raw electromyographic signal to the onset of the acoustic signal (AS) of the vowel under study (EMG to Audio-onset); the other is the time duration of muscular articulatory activity in which the raw EMG was measured from onset to offset (EMG duration).

The EMG time-onset and offset were decided according to the following procedures:

1. Generally visual observation of overall data collected in order to examine and differentiate among artifacts, prespeech potentials, and articulatory potentials;

2. After that, where spikes of electrical potential are crowded and amplitude continuously increases, a fine vertical line was drawn on the first spike of at least 3 mm. in vertical length which is considered in the present data collecting under Dr. Lubker's supervision as the onset of articulatory potential.

3. At the end of each syllabic utterance the muscular activation usually ceased while the last spike of the potential trace was at high amplitude. Thus, offset of the articulatory potential was decided where the spike of 3 mm. in length(or longer) disappeared. The onset of the acoustic signal (AS) was decided where the sign of acoustic trace appeared.

Then, the figures from the measurements were summed up into two statistical groups: one is Mean or normal average the other is Standard Deviation (SD) which indicates degree of variation among individual measurements. To obtain SD the following mathematical formular was employed:

$$SD = \frac{\Sigma x^2}{n} - (\bar{X})^2$$

x = an individual measurement

Σ = sum of squared individual measurements

n = number of one word uttered

$\bar{X}$ = mean of the five measurements

The other dimension is to establish the intensity pattern of the muscle activity or amount of the electromyographic potentials in time. The study was to be undertaken by comparing the averaged integrated curves (AIC). This aspect was made with the aid of the audio signal as a temperal reference for comparing EMG records.

Procedure of obtaining an averaged integrated curve.

The procedure which was without the assistance of computer processing at the time the investigation was carried on, was initiated and guided by the Stockholm research group. That is, a common base-line and the voicing onset (acoustic signal, AS) of the vowels were used as the line-up points. The integrated curve (IC) of each vowel utterance was carefully traced, then an averaged of 5 superimposed integrated curves was drawn. The curve obtained by this method is called an averaged integrated curve (AIC), see Fig XIII.

To study the intensity parameter of a single muscle required in the production of phonologically distinctive vowels, two uncomplicated diagnostic techniques were employed. One was for comparing the intensity of the activity between the vowels of different quantities, e.g. u:, u. This was carried out by simply superimposing the AIC of the vowels quantitatively paired and observing any differences which might occur. The other technique was used for comparing the intensity activity among the vowels of different quality. This was carried out by using the AIC of a close vowel as reference. The process was that the height of the reference vowel measured at every 40 msec. interval was subtracted from the height of the curve for each of the other vowels (Lubker, et al. 1974). The resulting series of differences were connected to form the difference curves (DC) see Fig. XIV. These curves are considered as the qualitative illustrations of different shape patterns of the electromyographic activity for the production of the vowels.

Though mannual analysis was employed in this presentation, computer analysis, the procedure by which relieves investigators of much tedious visual analysis, should also be briefly mentioned. That is inadequate programming, the lack of differentiating between artifacts and potentials will allow the machine to include artifacts. Thus, as Basmajian's warning (1974: 52) "... computer analysis without visual monitoring by an experienced person is fraught with errors".

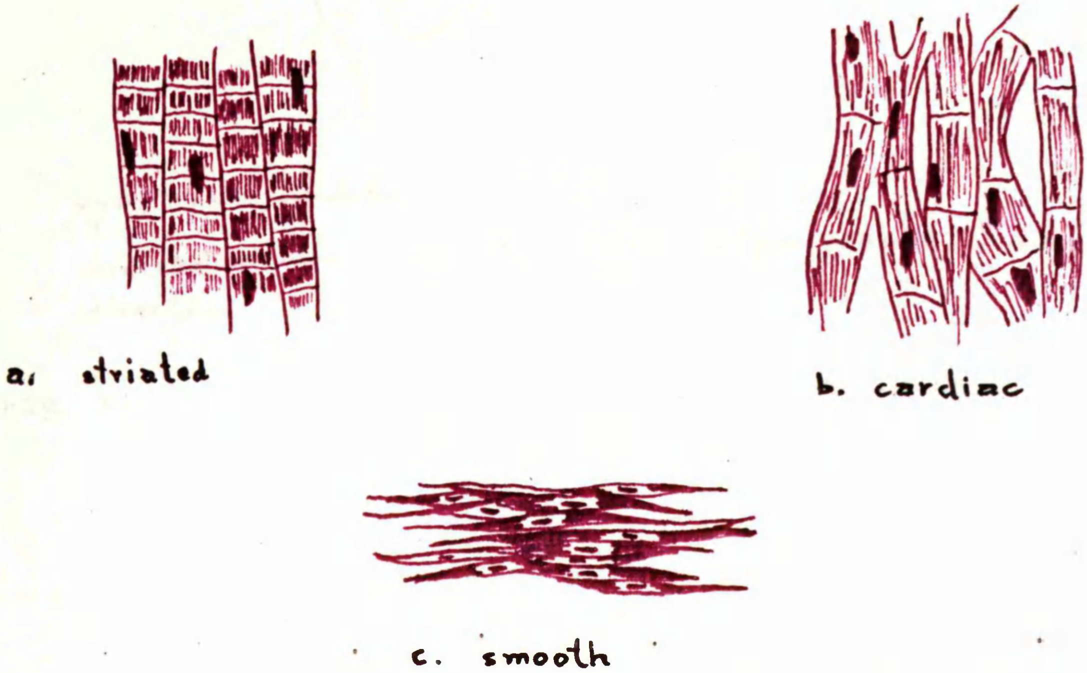


Fig. IV. Schemes of fibres of different kinds of muscle.

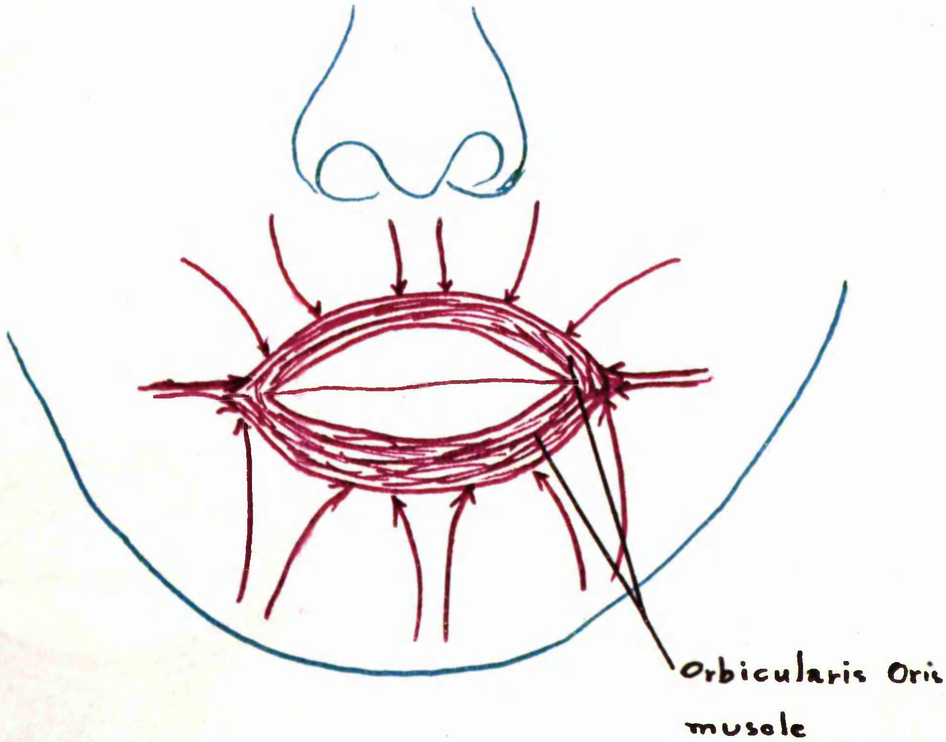


Fig. V. Schematic diagram of labial muscles.

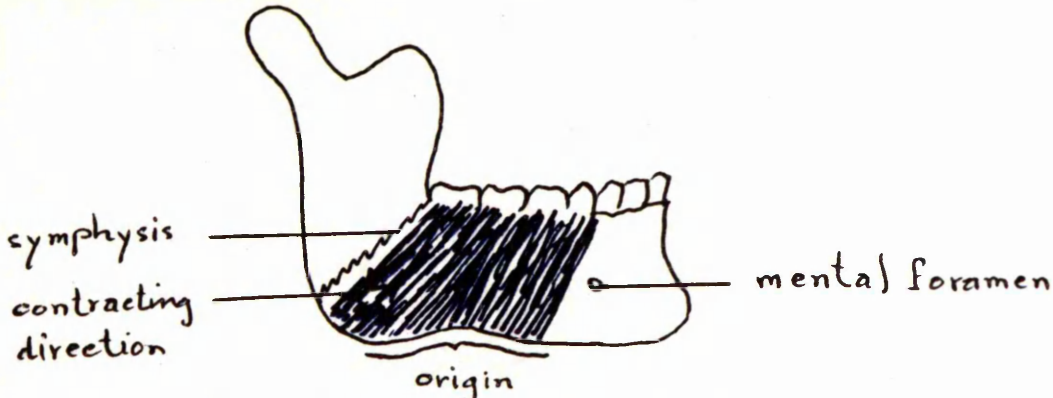


Fig. VI. Illustrating the location of M. Depressor Labii Inferioris and the direction of contraction.

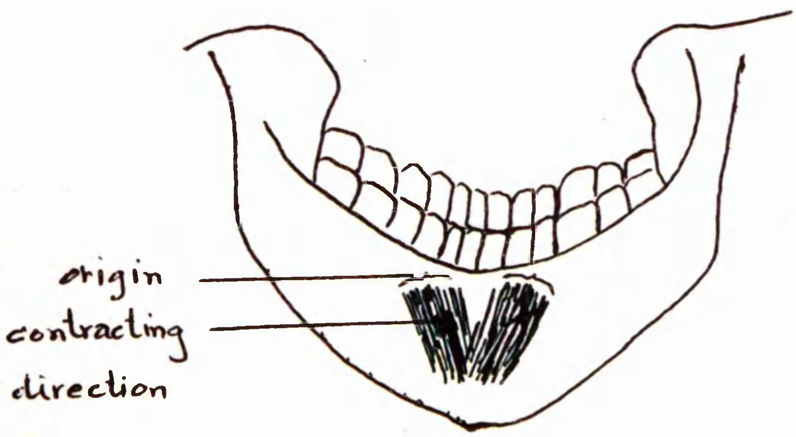


Fig. VII. Schematic diagram of M. Mentalis.

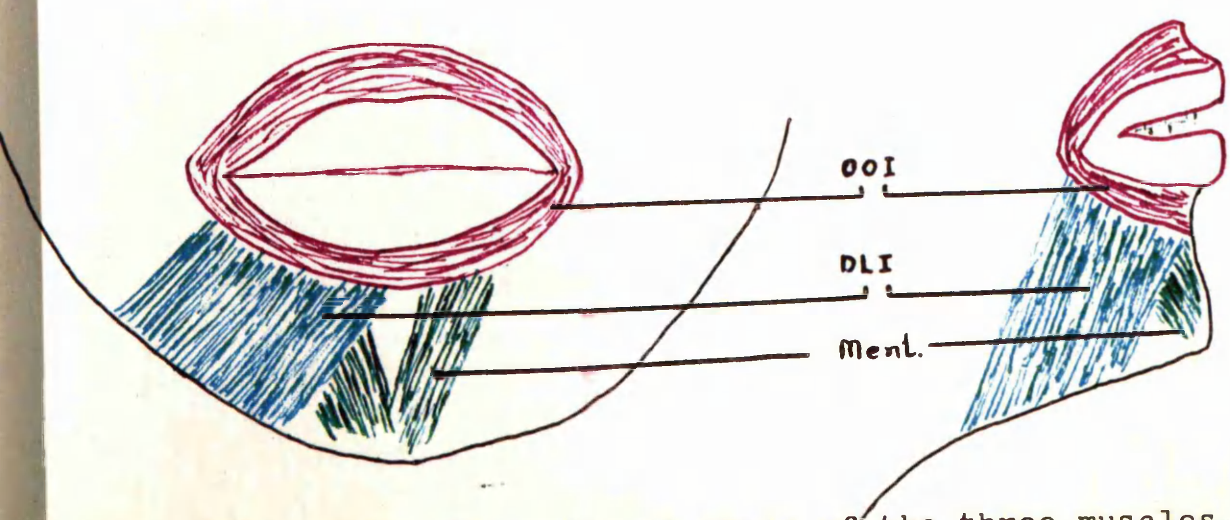


Fig. VIII. Schematic diagrams of the three muscles.

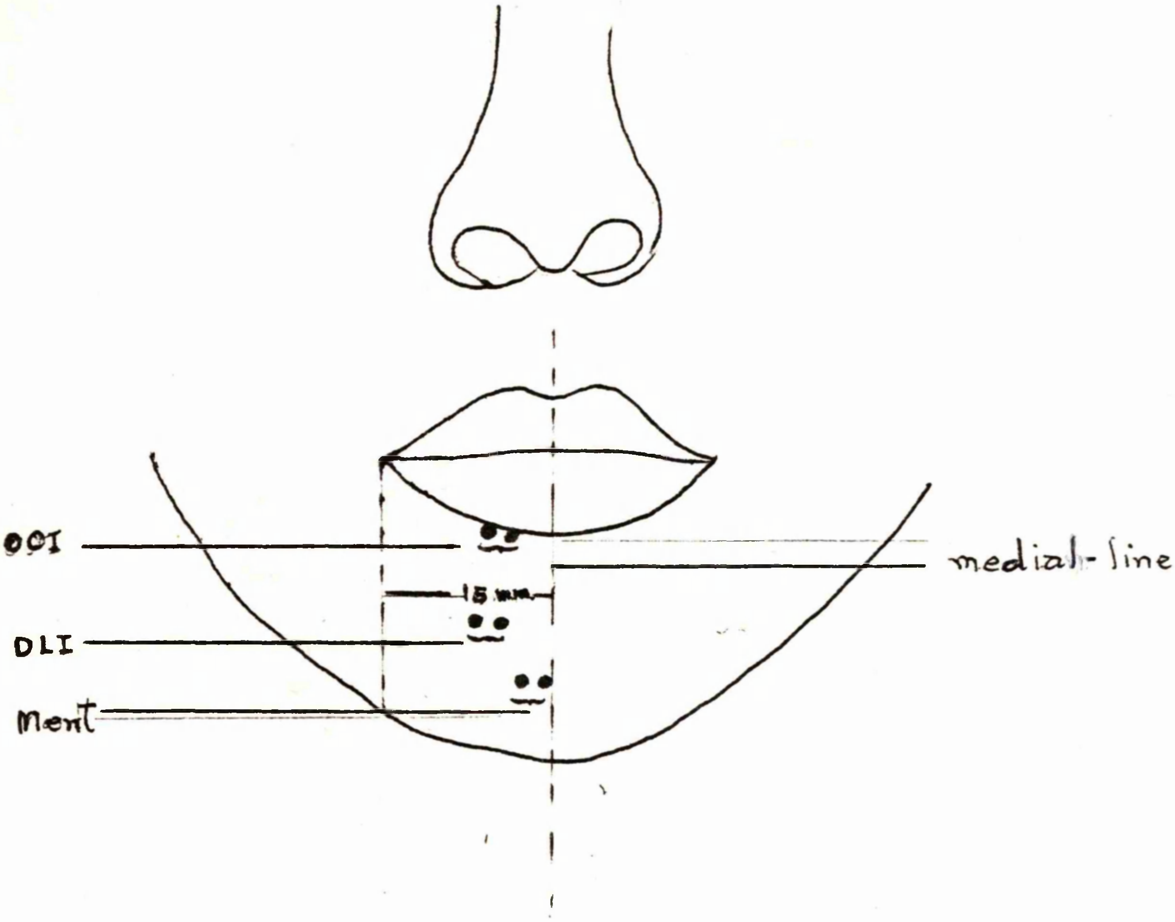


Fig. IX. Schematic diagram of the locations of the surface bipolar paint-on electrodes.

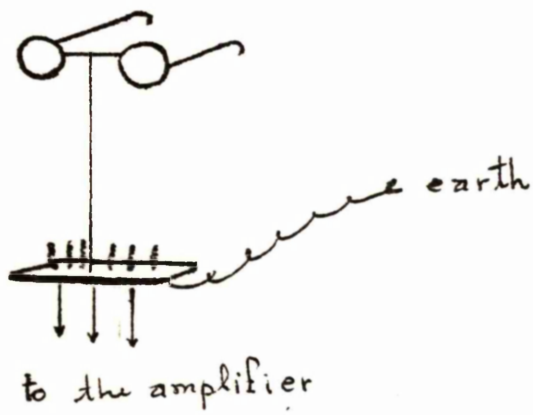
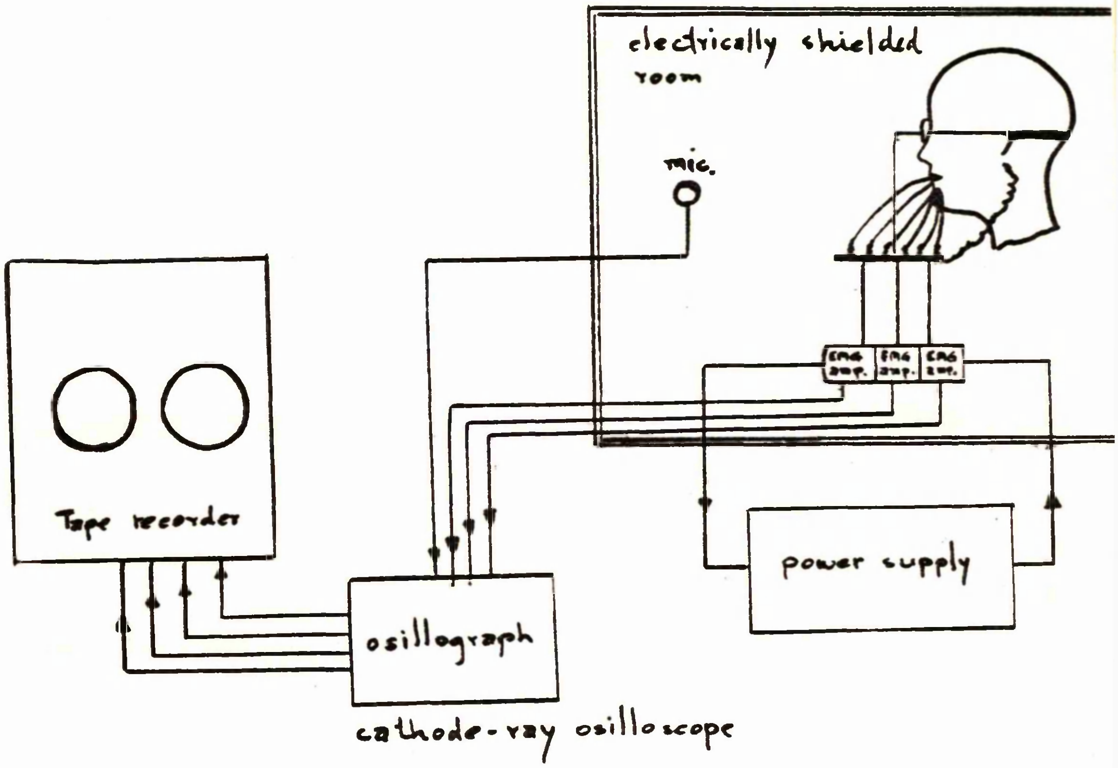


Fig. X. A diagram of the rack.



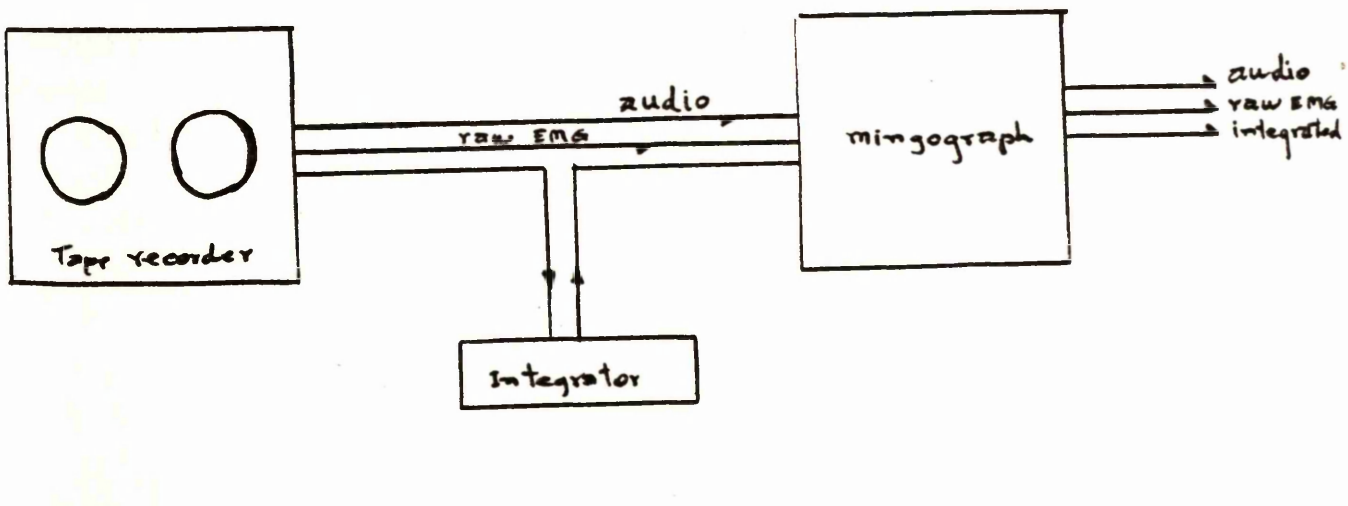
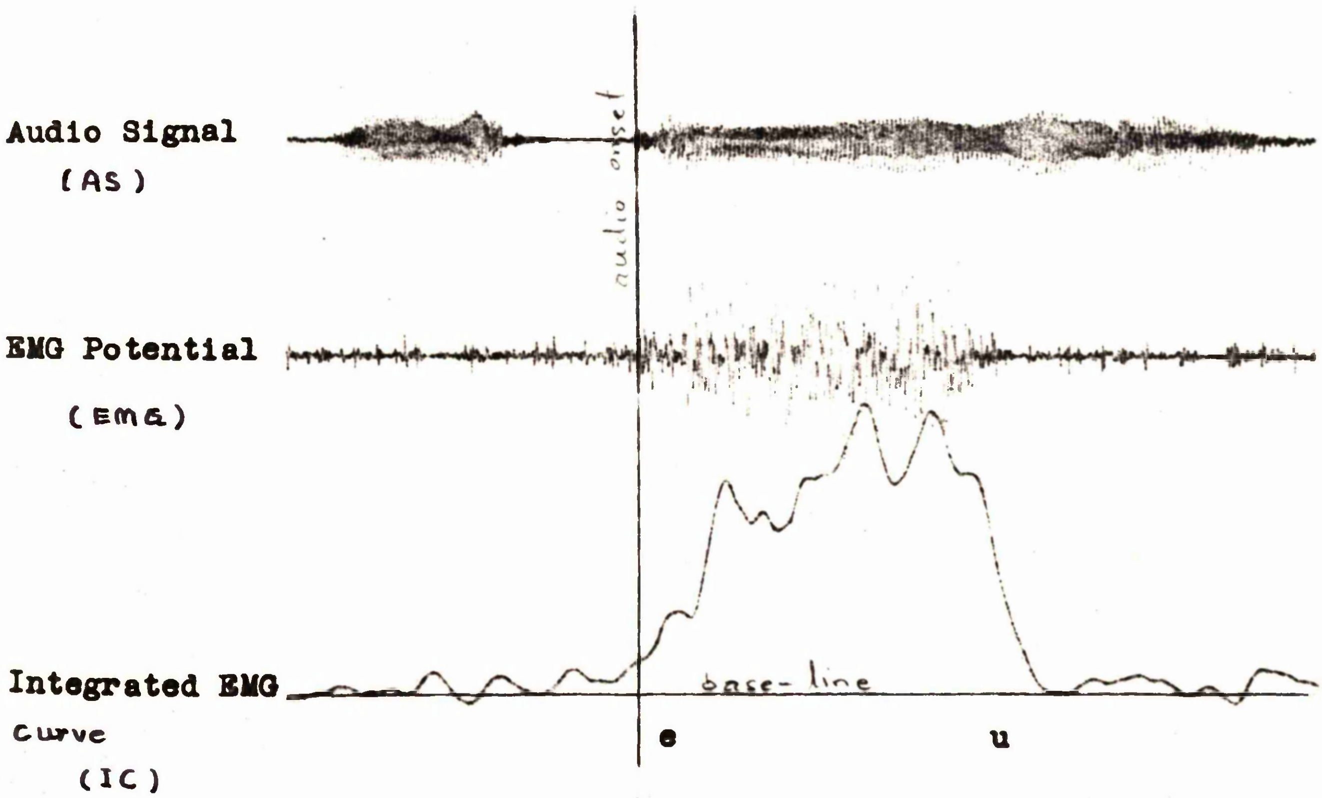


Fig. XI Schematic diagrams of the instrumentation.

EMG I



An illustration of Electromyogram.

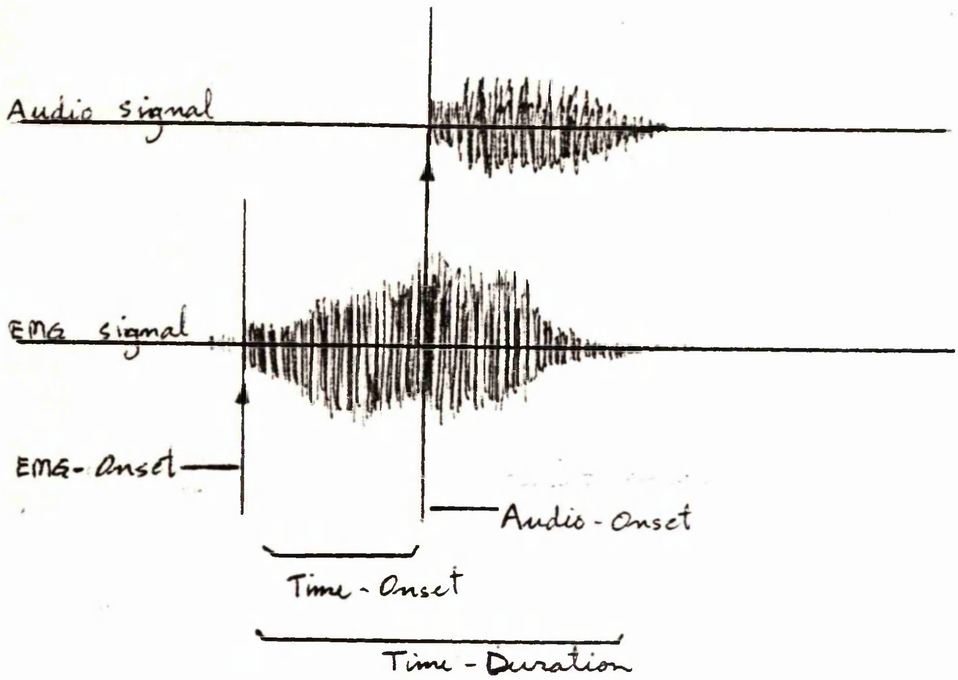


Fig. XII. Scheme of the time dimension measurements.

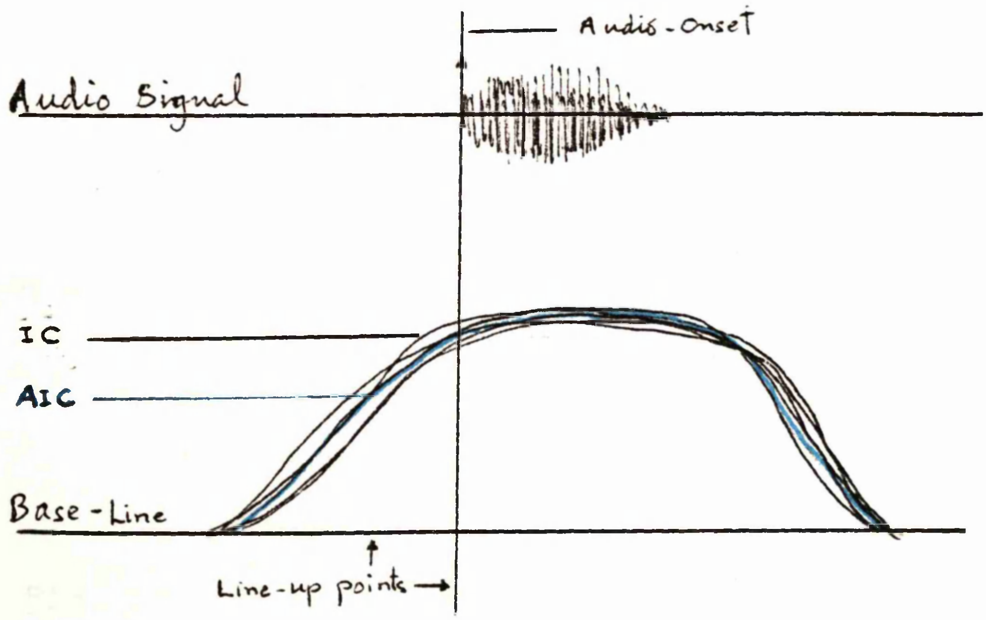
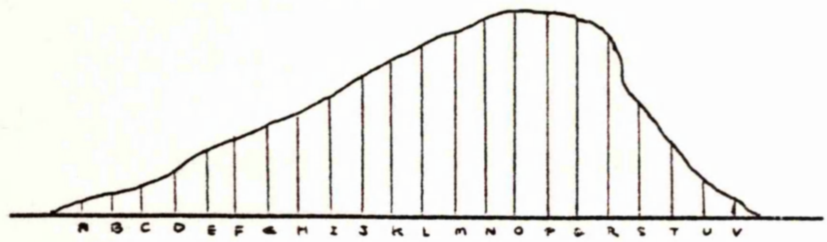
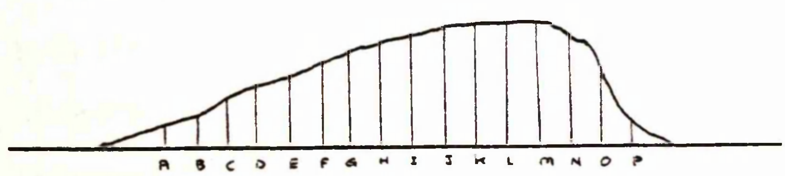


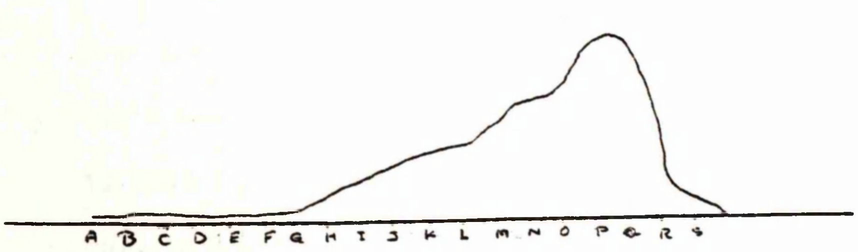
Fig. XIII. Scheme of the manual technique to obtain an averaged integrated curve (AIC).



a. averaged integrated curve A.
(measured at 40 msec. intervals).



b. averaged integrated curve B.



c. The Difference Curve of A and B.

Fig. XIV. The technique demonstrating how to obtain a Difference Curve (DC).

CHAPTER 3

REFERENCE OF THE STUDY "STANDARD THAI"

Broadly speaking the Thai dialects as spoken in Thailand have been recognised as of four main types; Central (including the dialect of the capital, Bangkok), Northern, Northeastern, and Southern. The Thai pronunciation employed in this study are those of "Standard Thai". The term "Standard Thai" is understandably attched to the Central dialect; however, it still needs more precise definition. Apparently what has been given as the definition of Standard Thai is only partially acceptable. For instance, Abramson (1962; 1) has said that "Standard Thai is the national language of Thailand and the dialect of the central region including the capital, Bangkok..." In fact, to be explicit, Standard Thai is not the dialect of the central region; it is one of the dialects of the central region. Noss (1964) states that it is the prestige dialect spoken by the highly educated people of Thailand, and that it most closely represents the regional dialect of the central plain centering around and including Bangkok. The problem is that it is rather doubtful whether Standard Thai is conined only to the group of highly educated. However, Beebe (1976) has proposed a somewhat negative definition,viz. "Standard Thai is not consistently spoken by anyone in normal conversation. Standard Thai, then, can only be defined as a set of convention believed to be correct by the educated of Bangkok".

Nevertheless, a reasonable explanation was given by Chittham (1974) that Standard Thai normally refers to the dialect spoken in the capital city, for example, when Ayuddaya was the capital city of the Thai kingdom, then the Ayuddaya dialect was the Standard Thai. At present, Bangkok is the capital city of the kingdom therefore Bangkok dialect, one of the Central dialects, is the standard dialect. Accordingly, one can conclude that the present Standard Thai was derived from the Bangkok dialect and has been used in education, official communication, and commercial activities between people of different parts of the country.

From a stylistic point of view, there seem to be two types of Standard Thai; one is employed in mass media, radio and T.V. broadcasting, and official speech delivery; the other is casually used in daily living. As Henderson (1949) classified the Thai speech into three styles; isolative, combinative and rapid combinative; it seems that the isolative and the combinative can be categorised as the official style. The rapid combinative style can be either official or casual style depending on the speech habit of the speakers.

The subject's speech used in this investigation is categorised as being in the isolative style which was defined by Henderson (1949: 189) "It is that commonly used for monosyllabic words and for the slow, deliberate pronunciation of polysyllables, and is that shown in dictionaries." The structure of the syllable which is also that of the monosyllabic word, is determined by reference to the isolative style only. Personally the subject's style of speaking is relatively slow. Having been brought up and educated in a Standard Thai-speaking linguistic environment, Standard Thai is the only dialect acquired by the subject. The subject did not leave for study abroad until she had completed her Bachelor's degree, the course of which may be considered as consolidating a firm competence and performance in the native tongue. The kind of Standard Thai employed in this electromyographic investigation is thus believed to be free from the influence of regional and foreign accents.

Concerning the material used in the study, the analysis was confined to short utterances. To avoid possible interference from neighbouring articulations the syllables to be investigated were embedded in the fixed context: thâ:...là; which may be loosely translated a " What about...? "

Since the study was concentrated on vowel production, the consonantal segments had to be those of nonlabial type. In this investigation the glottal stop[ʔ] and the unaspirated velar stop[k]were chosen as the initial consonants in the utterances of mostly meaningful words*. The utterances were read one after another and they were consecutively repeated five times.

The phonetic transcription employed in this work follows that of Henderson (1949: 189-215) except the tone marker system which follows that of Haas (1946: 127).

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* A few are meaningless because there happens to be no words of a particular structure.

Phonetic transcription and glossaries of the syllables containing the monophthongs investigated:

Transcriptions			Glossaries
thâ:	?i:	là:	high front long vowel
	?ì?		high front short vowel
	?e:		being puzzled
	?é?		moody expression
	?ɛ̂:		overloaded
	?ɛ̀?		unpleasant expression
	?ɯ:		it seems reasonable.
	?ɯ̀?		excrement
	?ɤ̀:		overflow
	?ɤ̀		surprising expression
	?a:		father's younger brother
	?à?		stuttering expression
	?ù:		garage
	?ù?		wine made from glutenous rice
	?ò:		a feeling of being elegant
	?ó?		surprising expression
	?ɔ̌:		understanding expression
	*?ɔ?		-

Tone markers:	
mid level	blank
falling	`
high rising	´
falling rising	ˇ
rising falling	^

Phonetic transcription and glossaries of the syllables containing the monophthongs investigated (cont.):

Transcriptions	Glossaries
thâ: kì là:	a question word as "how many or much"
*kìʔ	-
ké:	fake
kéʔ	a Chinese loan word for "withdrawer"
kɛ̂:	old age
kɛ̀ʔ	sheep, craving
*kɯ̀:	-
*kɯ̀ʔ	-
kɤ̂:	embarrassing
kɤ̀ʔ	informal for klɤ̀ʔ means filthy
ka:	crows
kàʔ	shift work, approximation
kù:	calling for someone far away
kùʔ	making up
kô:	elegant
*kóʔ	-
kɔ̀:	building up in a small scale
kɔ̀ʔ	an island, to bug

Footnote: Some exprlanation of the presence of the final [ʔ] in short vowels is called for. Short vowels in Thai, are always pronounced with a following glottal stop when no other consonants follow. Long vowels may occur without any following sound.

Phonetic transcription and glossaries of the syllables containing the diphthongs and triphthongs investigated.

Diphthongs	Transcriptions		Glossaries
thâ:	*?i:a	ìa:	-
	?ɯ̂a		kindly
	?úa		a Chinese loan word used as "I"
	?íu		shamful
	?eu		waist
	?ɛ̌u		a pet name
	?úi		surprising expression
	?o:i		painful expression
	?ɔ̌i		bright yellow.
	?ai		to cough, steam
	?ɤ:i		word ending used in poem, classical songs
	?au		possessing
	ki:a		an English loan word for "auto-gear"
	kɯ̂a		kindly support
	kua		an informal for "klua" means afraid of
	kìu		nearly falling apart
	*keu		-
	kɛ̂:u		glass
	kúi		hoolligans
	ko:i		quickly run away
	kɔ̂i		little finger
	kai		body
	kɤ:i		overlapping
	kau		to scratch

Phonetic transcription and glossaries of the syllables containing the triphthongs investigated.

Transcriptions	Glossaries
thâ: *ʔɯai làː	-
ʔîau	partially turn around
ʔuai	a pot (enamel ware)
*kɯai	-
kîau	courtship
kûai	informal for "klûai" means bananas

Footnote: Though the Thai language is a Tone language, there is no tonal effect involved in the activity of labial musculature.

CHAPTER 4

THE STUDY OF ORBICULARIS ORIS INFERIORIS (OOI) MUSCLE ACTIVITY IN MONOPHTHONGS

Introductory discussion of "Rounding"

When rounding is visually observed one can only see the gesture of the orbicularis oris muscles. From the articulatory points of view, the muscles play an important role in performing the rounding configurations. The study of the muscle action potentials, therefore, is concerned about the two aspects namely, time dimension and intensity dimension. By studying the time dimension the concentrations will be on two areas. One will be dealing with activity in relation to the audio onset. The other will be on the durational activity of the muscle during the productions of the vowels.

Traditionally, one popularity hypothesis is that vowels can be specified in terms of the "position" and"height" of the "point of constriction" of the tongue. Concerning traditional discussion of rounding gesture has mentioned merely the exterior characteristic of the lip orifice. Sweet (1906:16) defined rounding as "...a narrowing of the mouth opening by approximation of the lips". He furthermore classified rounding: "inner and outer". Sweet (1906:17) described deliberately that "In outer rounding with which front vowels are rounded - the lips are brought together vertically...Back and mixed vowels are rounded by lateral compression of the corners of the mouth". He also categorised rounding in speech into three degrees correlated with the height of the tongue: high vowels having the narrowest, low the widest lip aperture. He provided the examples of the high-back-round as in good, the mid-back-round in no, and the low-back-round in not, (Sweet 1906:16).

According to Daniel Jones's cardinal vowel system there are also three degrees of cardinal rounding for [u] [o], and [ɔ], according to the width of the lip aperture respectively.

The American phonetician, Pike (1971: 14-15) gave the description of Lip Modifications of Vocoids that "Some vocoids have the lips rounded during their pronunciation. If the opening is large they are only slightly rounded.. If the opening between the lips is small and round the vocoids are heavily rounded." Pike classified lip gestures into five degrees in which three require rounding gesture.

Apparently, these traditional labial descriptions rely almost entirely on visual observations of the articulatory gestures.

Jakobson, Fant and Halle (1967:9) assigned the distinctive features based on acoustical characteristics "Flat" and "Plain" to the rounding and the spreading, as they said: "There is a continuous variation in the shape of the lips from a close rounding to spreading...but the linguistic assignment of distinctive value to two distant lip positions and to their contrastive acoustical effects.".

In Chomsky and Halle's The Sound Pattern of English, in spite of regarding the phonetic features as physical scales they assigned to the lip posture a binary feature, which means that [u], [o] and [ɔ] possess the same rounding feature, + rounding.

With the application of electromyography the insight into rounding posture is more elaborately exposed and supplies a more sophisticated description of the phenomenon. The interesting points frequently found in the electromyography literature concern the time-onset of the muscular activity and the muscular tension of the activity in speech. In terms of timing, all the electromyographic reports are agreed that anticipatory movements of labial muscles start prior to the onset of the audio signal of the speech sound; meanwhile, research on muscular tension in speech needs more elaborate investigation techniques.

Data presentation.

Generally, the figures collected in the following Tables are based on those of the vowels traditionally classified as rounded. However, the muscular activity investigated by the use of electromyographic techniques demonstrates that there are several characteristics to be mentioned besides the single simple descriptive term "Round".

As already stated in chapter 1, the muscular activity is viewed in two dimensions: the time dimension, and the intensity dimension. The time dimension is studied in two sections, one dealing with time-onset (the relation of EMG onset to Audio onset), and the other dealing with duration; i.e. the duration of muscular activity in the syllables investigated.

OOI muscle activity for monophthongs

Time dimension.

Time onset: EMG onset to Audio onset in msec.

Table 1 OOI anticipation for rounding gesture in monophthongs (five utterances)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	230		1	270
	2	268		2	260
	3	165		3	257
?ù:	4	185	kù:	4	210
	5	230		5	300
	average	216		average	259
	SD	36.49		SD	29.13
	1	330		1	310
	2	240		2	195
?ù?	3	170	kù?	3	282
	4	165		4	243
	5	185		5	278
	average	218		average	262
	SD	62.2		SD	39.52
	1	153		1	208
	2	198		2	205
	3	137		3	230
?ò:	4	184	kô:	4	300
	5	222		5	234
	average	179		average	235
	SD	30.58		SD	34.2

PT = Phonetic Transcription

Ao = Audio onset

Table 1 OOI anticipation for rounding gesture in monophthongs (cont.)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	245		1	303
	2	236		2	240
	3	290		3	215
ʔóʔ	4	200	kóʔ	4	247
	5	205		5	260
	average	235		average	253
	SD	32.40		SD	28.97
	1	200		1	185
	2	160		2	254
	3	144		3	160
ʔɔ̌:	4	157	kɔ̀:	4	250
	5	176		5	214
	average	167		average	212
	SD	19.22		SD	36.45
	1	200		1	240
	2	170		2	205
	3	160		3	150
ʔɔ̀ʔ	4	160	kɔ̀ʔ	4	240
	5	185		5	250
	average	165		average	217
	SD	27.20		SD	36.82

Comments on Table 1.

Obviously all the rounding activity began prior to the acoustic signals of the vowels. Comparing the figures for [u], [o] and [ɔ] the anticipatory activities of the articulations seem to be the shortest. Another point of interest is that the rounded vowels preceded by [k] have longer time onset than the vowels preceded by [ʔ]. Another point is that SD figures of short vowels is generally higher than those of long counterparts. It means that variation among the short vowels is higher than that of the long vowels. One reason may due to motor commands for the abrupt muscular action are not as steady as for longer muscular action.

Time dimension of the OOI muscular activity.

Duration of the syllables containing rounded monophthongs (in msec.)

Table 2 OOI duration of rounded monophthongs (five utterances)

PT	utterance order	EMG duration	PT	utterance order	EMG duration
	1	590		1	598
	2	665		2	580
	3	480		3	610
?ù:	4	500	kù:	4	565
	5	570		5	643
	average	561		average	599
	SD	66.36		SD	26.74
	1	550		1	570
	2	490		2	445
	3	390		3	550
?ù?	4	440	kù?	4	510
	5	440		5	512
	average	462		average	517
	SD	54.18		SD	42.79
	1	530		1	555
	2	530		2	515
	3	455		3	585
?ò:	4	515	kô:	4	650
	5	540		5	600
	average	514		average	581
	SD	30.56		SD	45.10

PT = Phonetic Transcription
Ao = Audio onset

Table 2 OOI duration of rounded monophthongs (cont.)

PT	utterance order	EMG duration	PT	utterance order	EMG duration
	1	495		1	530
	2	460		2	500
	3	530		3	460
ʔóʔ	4	460	kóʔ	4	495
	5	440		5	560
	average	477		average	501
	SD	31.87		SD	40.30
	1	410		1	570
	2	440		2	530
	3	413		3	444
ʔɔ̌ː	4	410	kɔ̀ː	4	550
	5	470		5	535
	average	428.6		average	526
	SD	23.58		SD	43.20
	1	385		1	420
	2	410		2	400
	3	365		3	330
ʔɔ̀ʔ	4	345	kɔ̀ʔ	4	390
	5	360		5	480
	average	373		average	404
	SD	22.49		SD	48.41

Comments on Table 2.

Those results are quite different from the acoustical evidence presented by Abramson (1962: 86-90) that the duration of the short vowels seems to be half as long as that of the long ones. From the electromyograms, the averaged durations of the short vowels do not appear to be half that of the long vowels. The durations of the long vowels are approximately 13-18 percent longer than those of the short ones. The durations are the shortest among the averaged durations of [u],

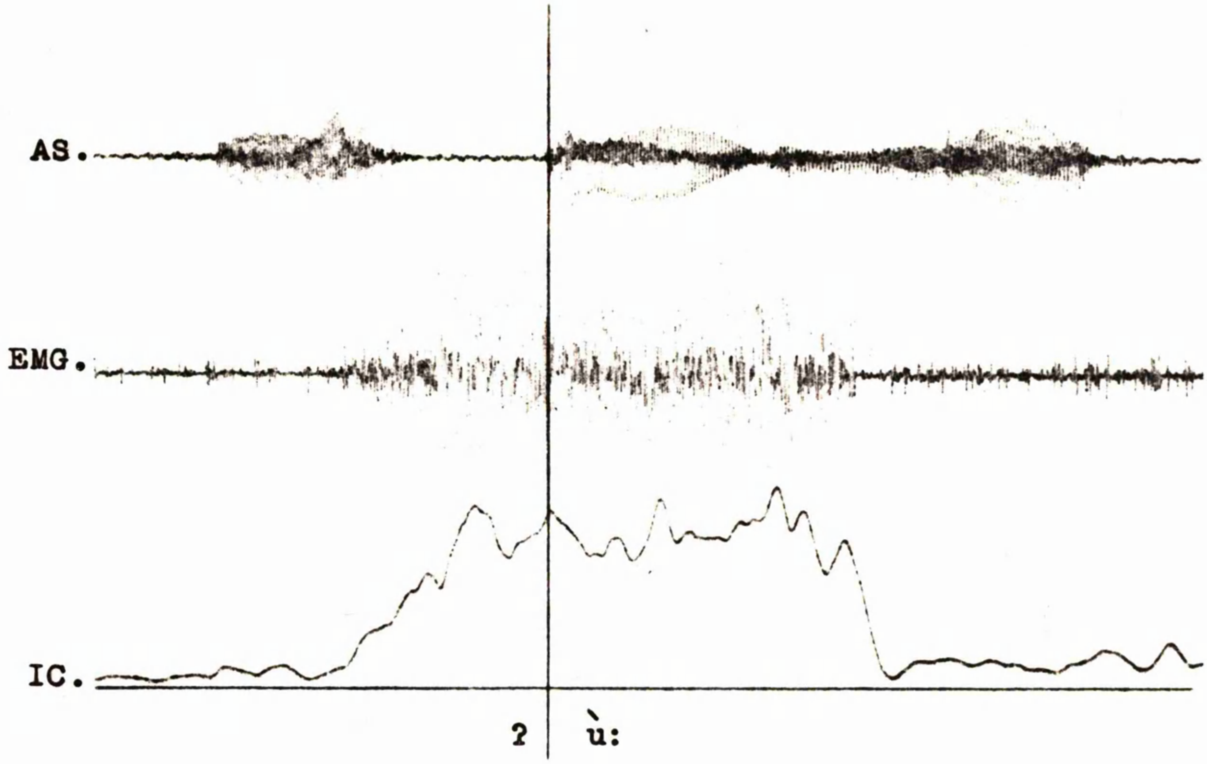
[ʊ] and [ɔ]. It is also evident that the vowels preceded by [k] are of longer duration than the vowels preceded by [?] approximately 7-18 percent. However, from SD figures, there is no fixed pattern that the durations of short vowels vary more than those of long vowels; either the figures do not clearly indicate whether the variation among the [?] syllables or the [k] syllables is higher. Besides, it should be mentioned here that the SD figures of [u:] and [u] display high variation among the back rounded vowels.

EMG traces of monophthongs.

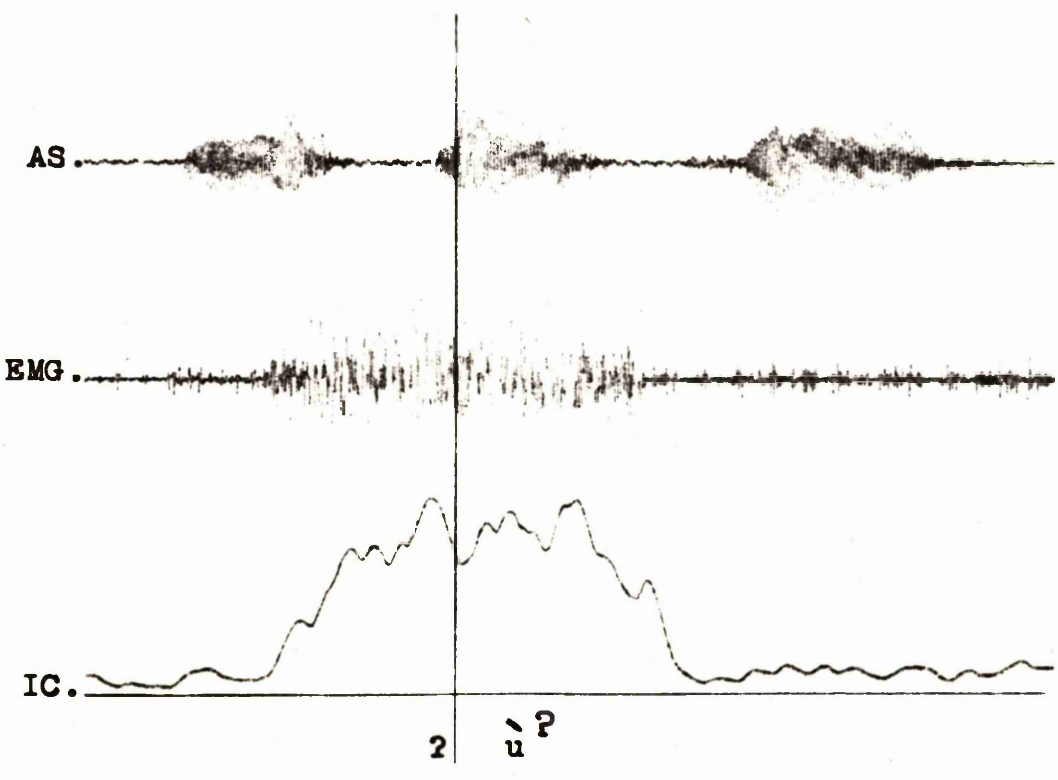
The following EMG traces II-VII show the OOI muscle activity in the rounded monophthongs.

The EMG traces VIII-XIX for the back unrounded and front vowels show, not surprisingly, no evidence of OOI muscle activity in these vowels.

EMG II

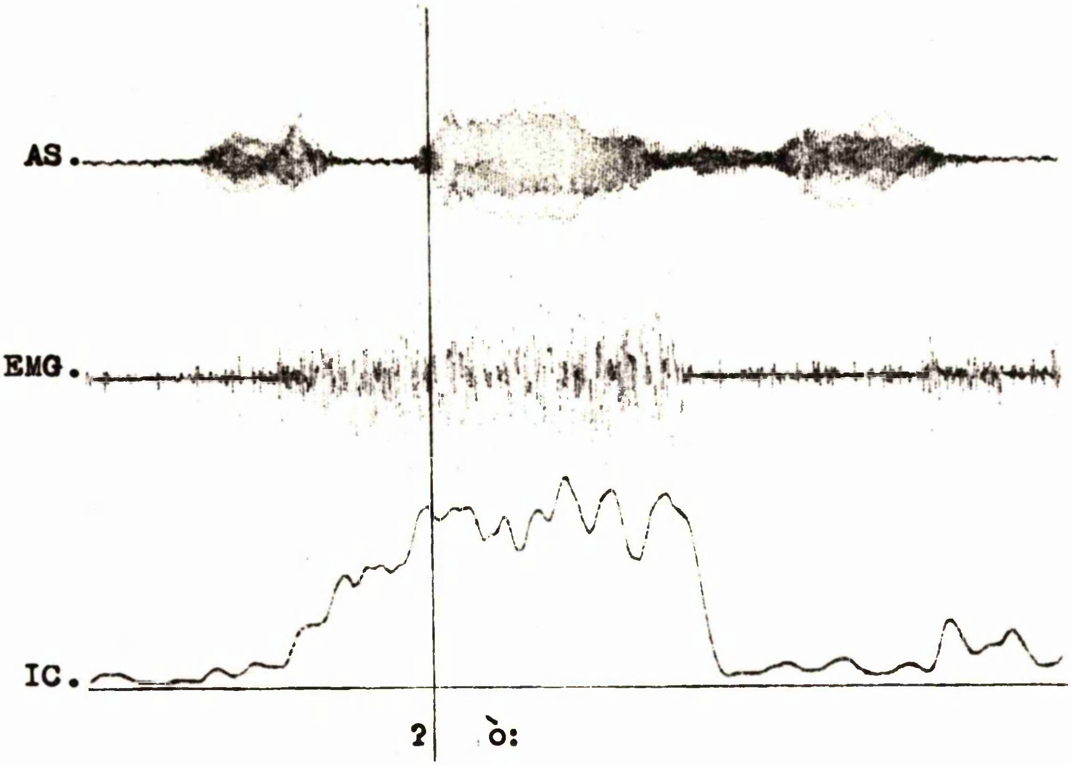


(a)

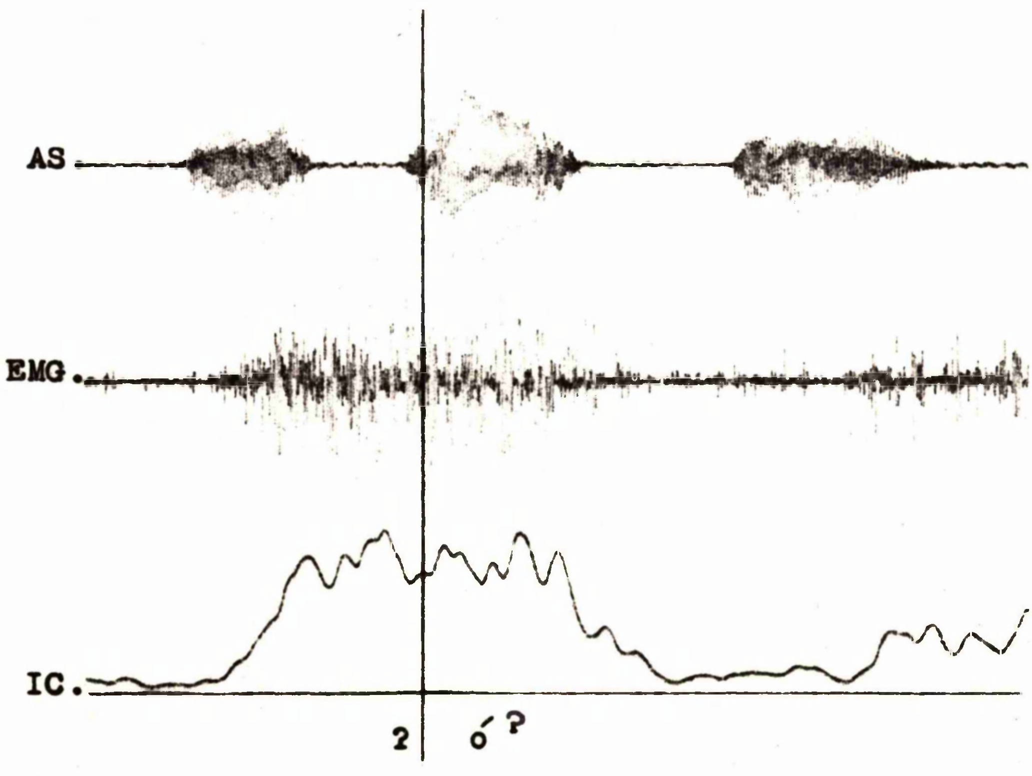


(b)

EMG III

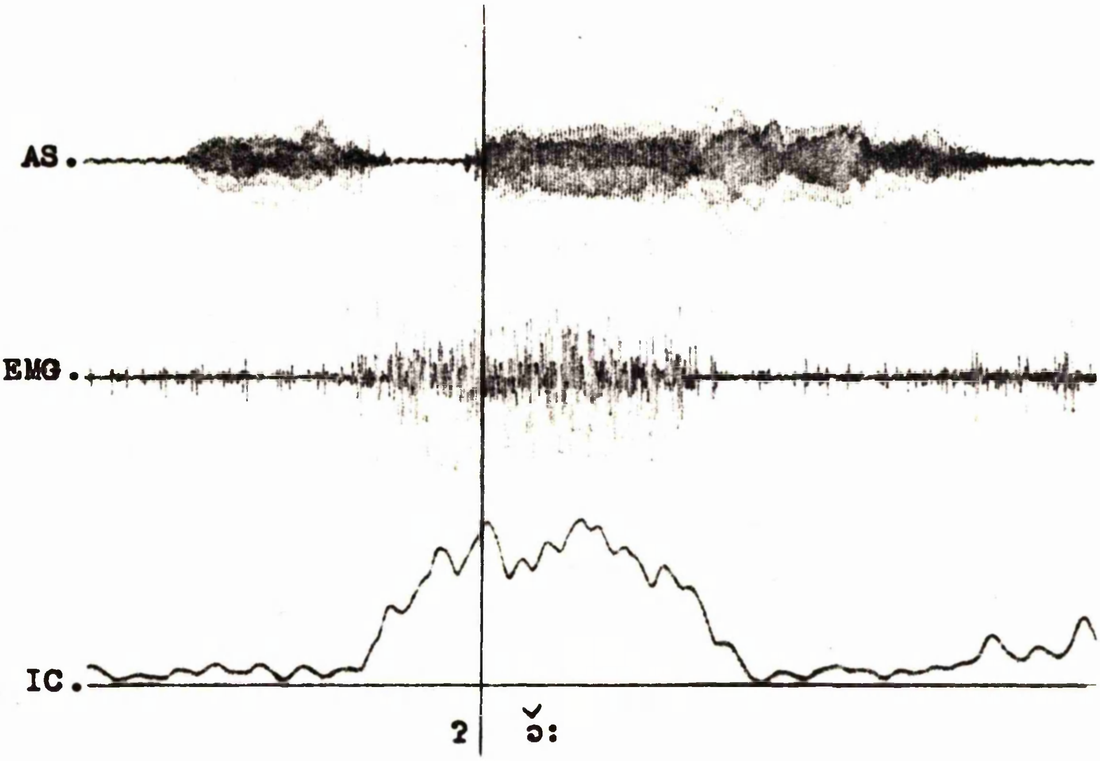


(a)

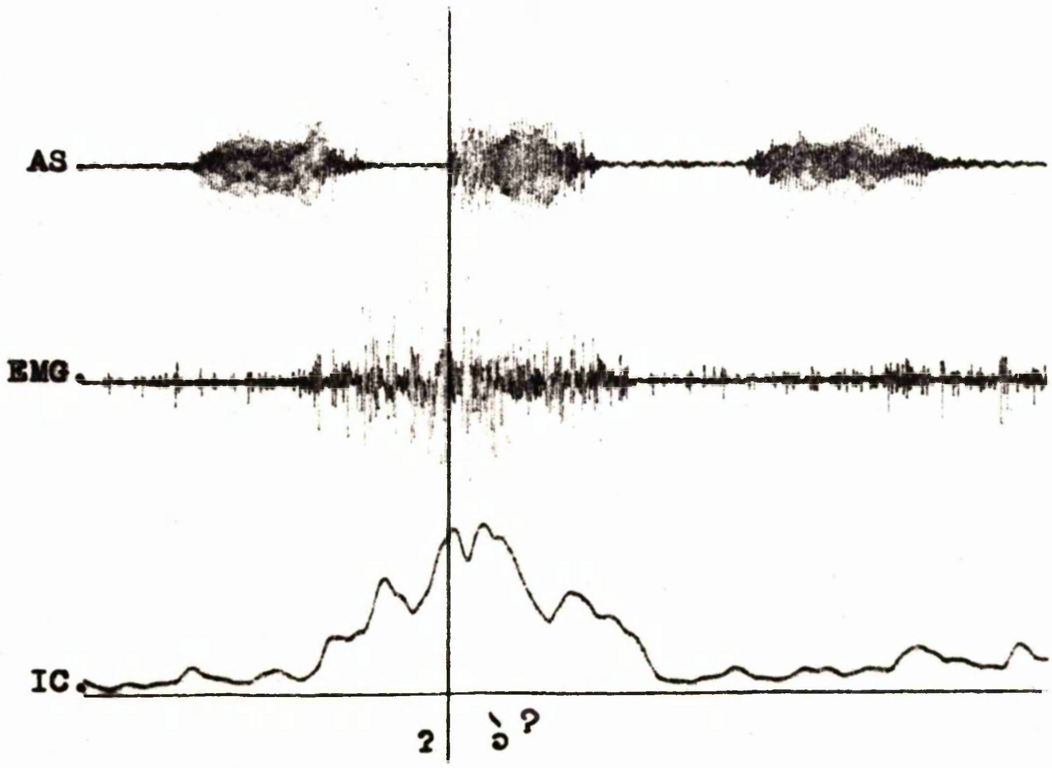


(b)

EMG IV

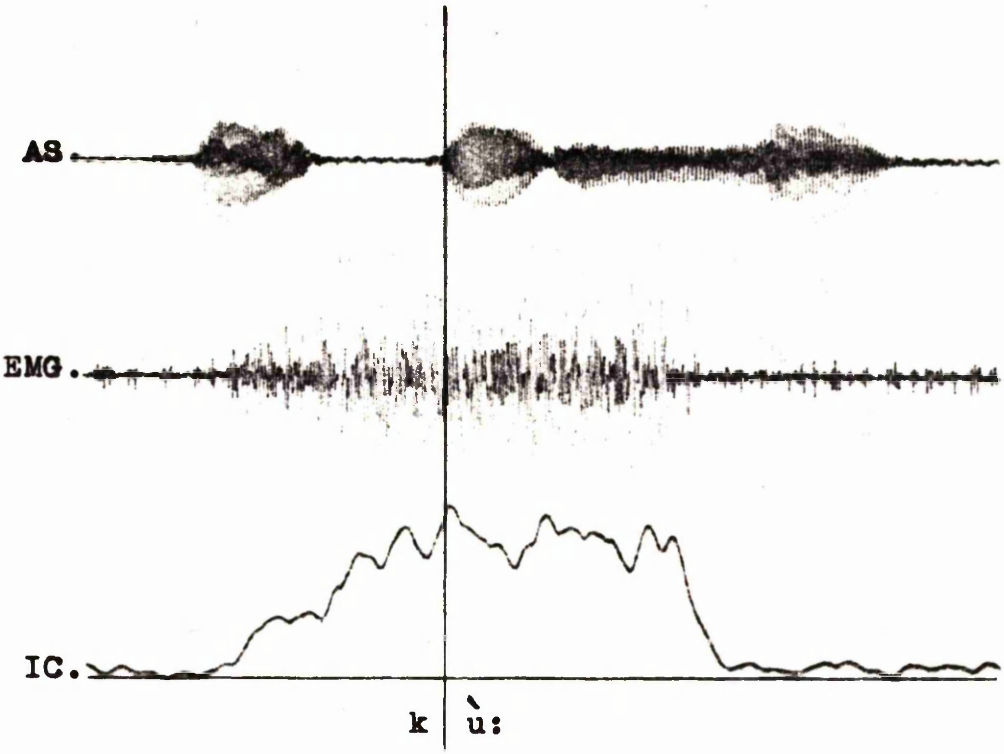


(a)

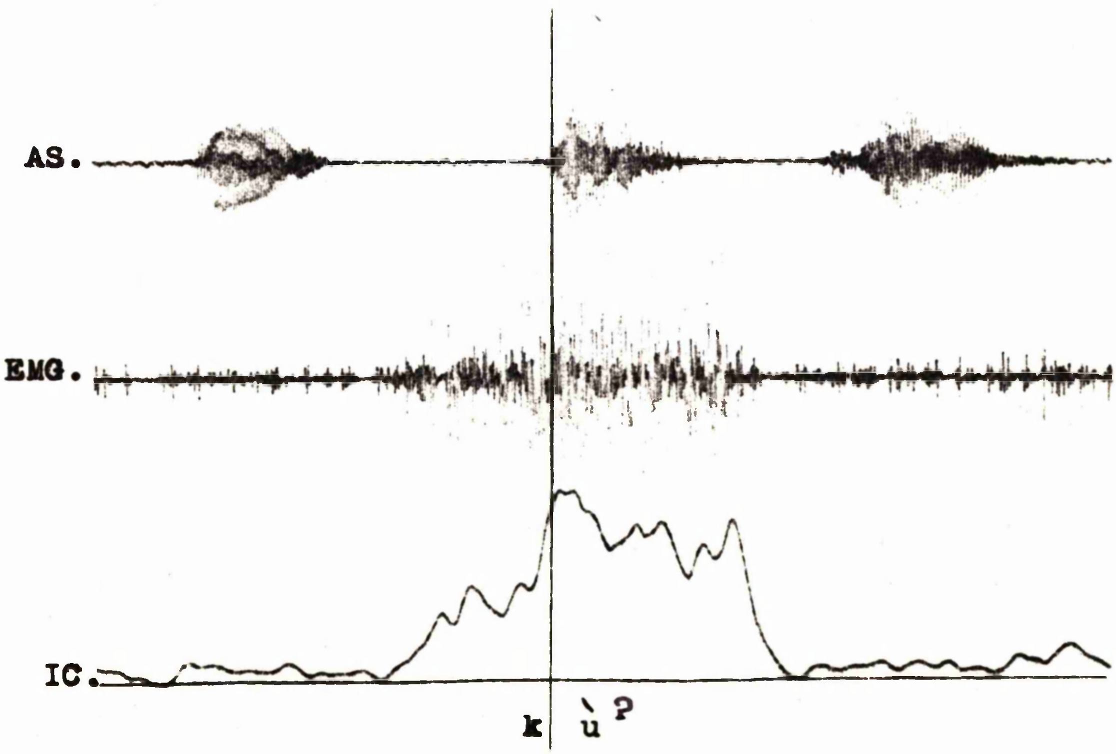


(b)

EMG V

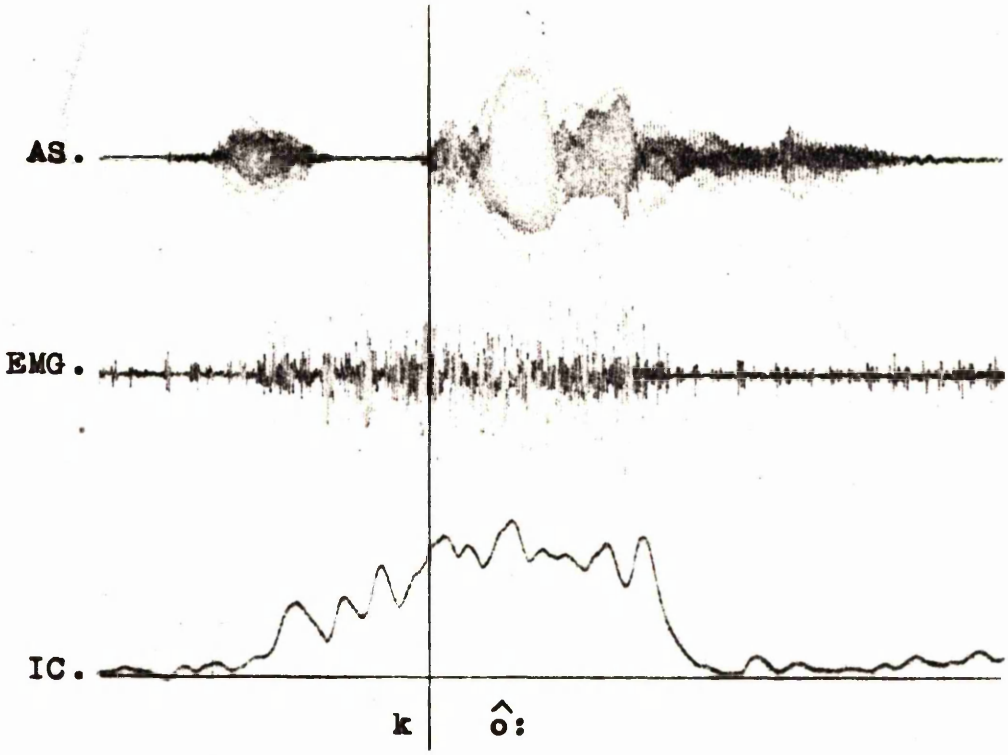


(a)

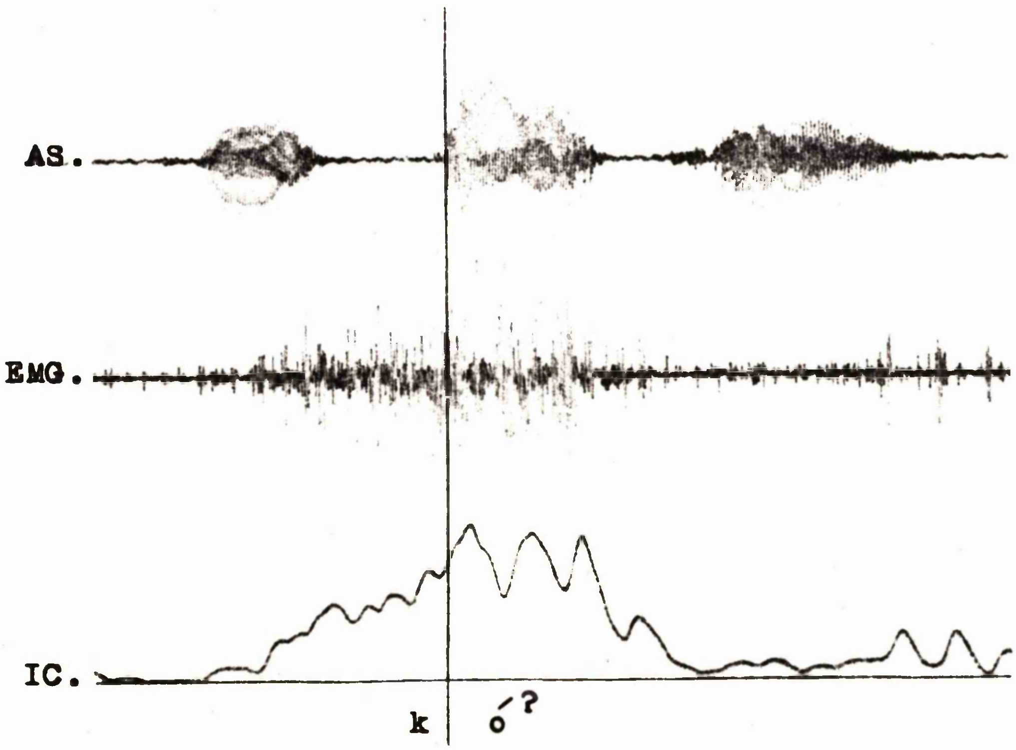


(b)

EMG VI

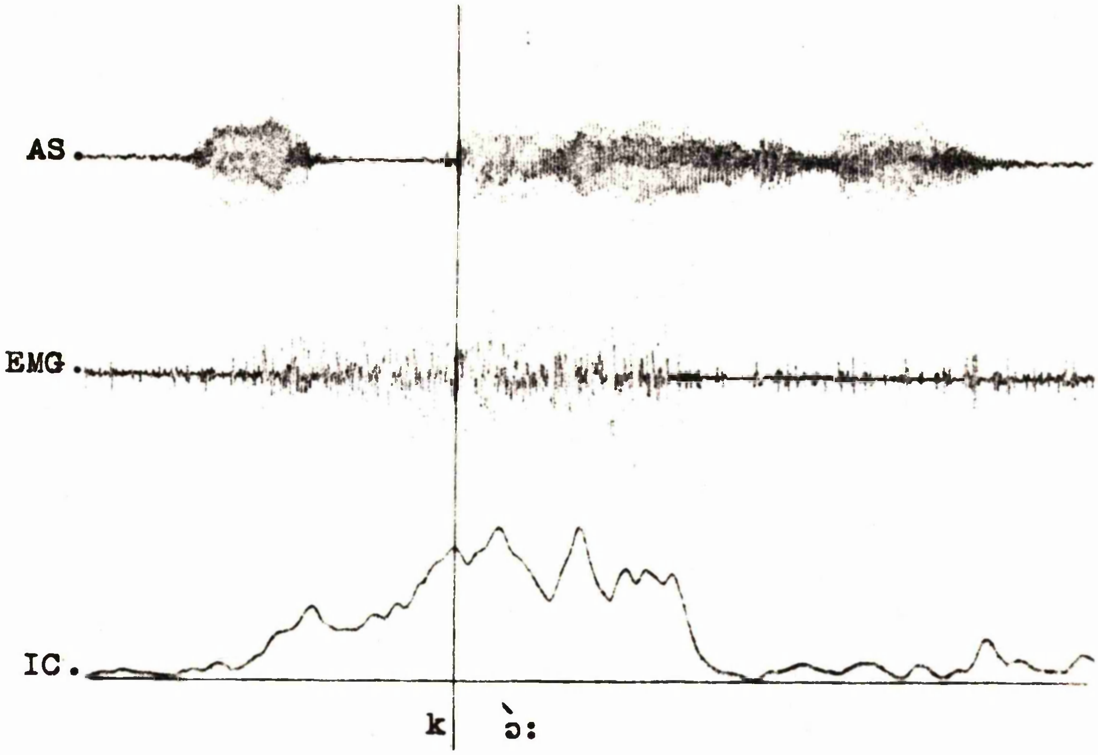


(a)

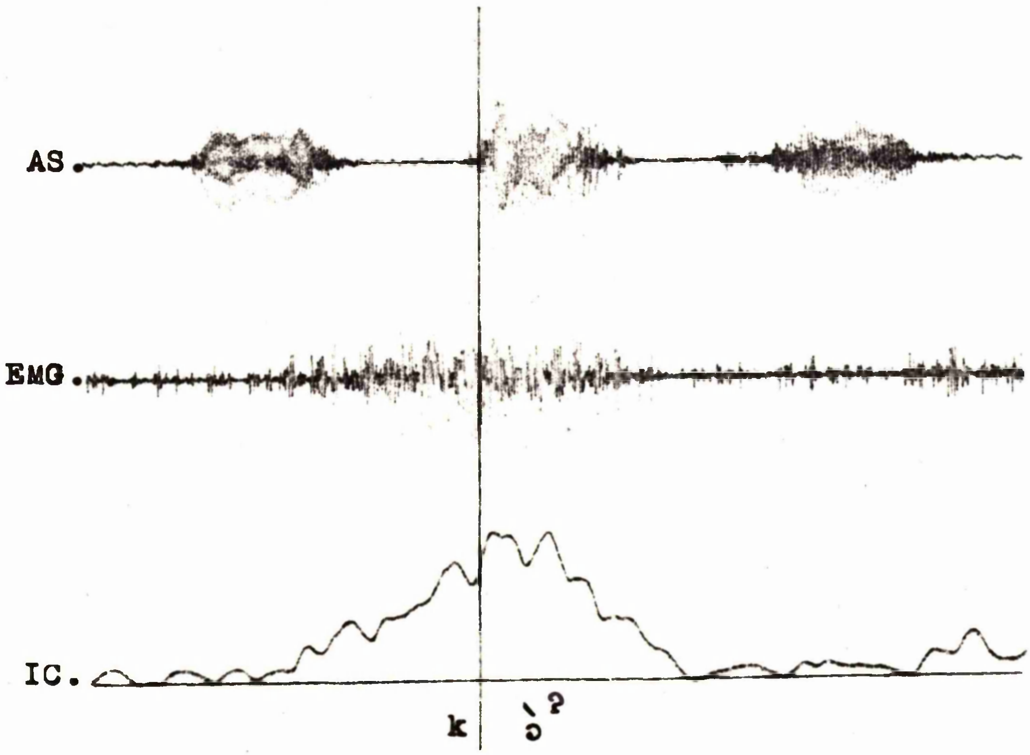


(b)

EMG VII

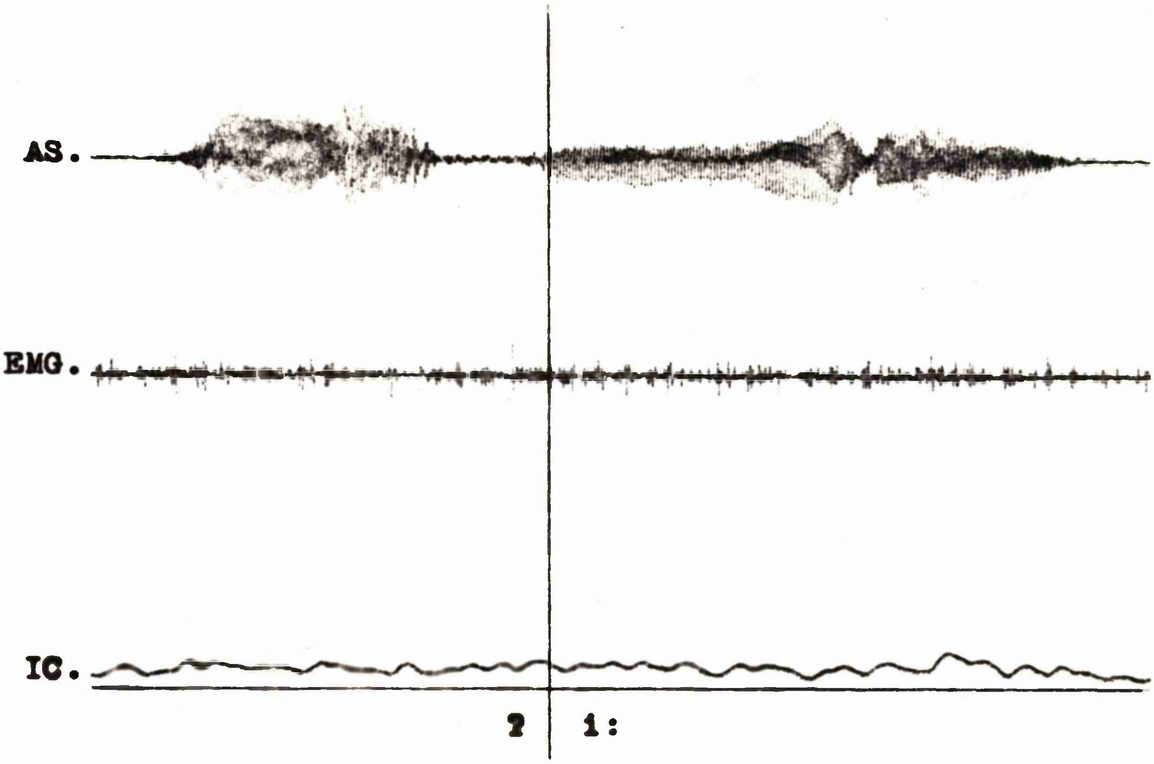


(a)

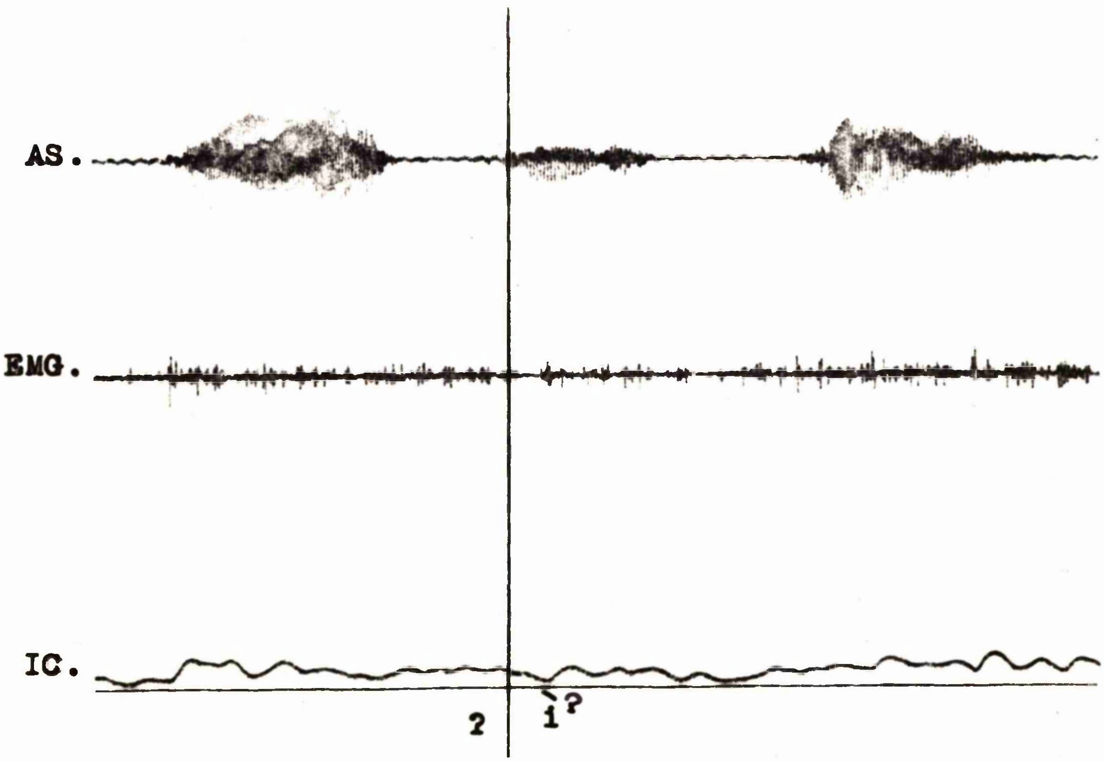


(b)

EMG VIII

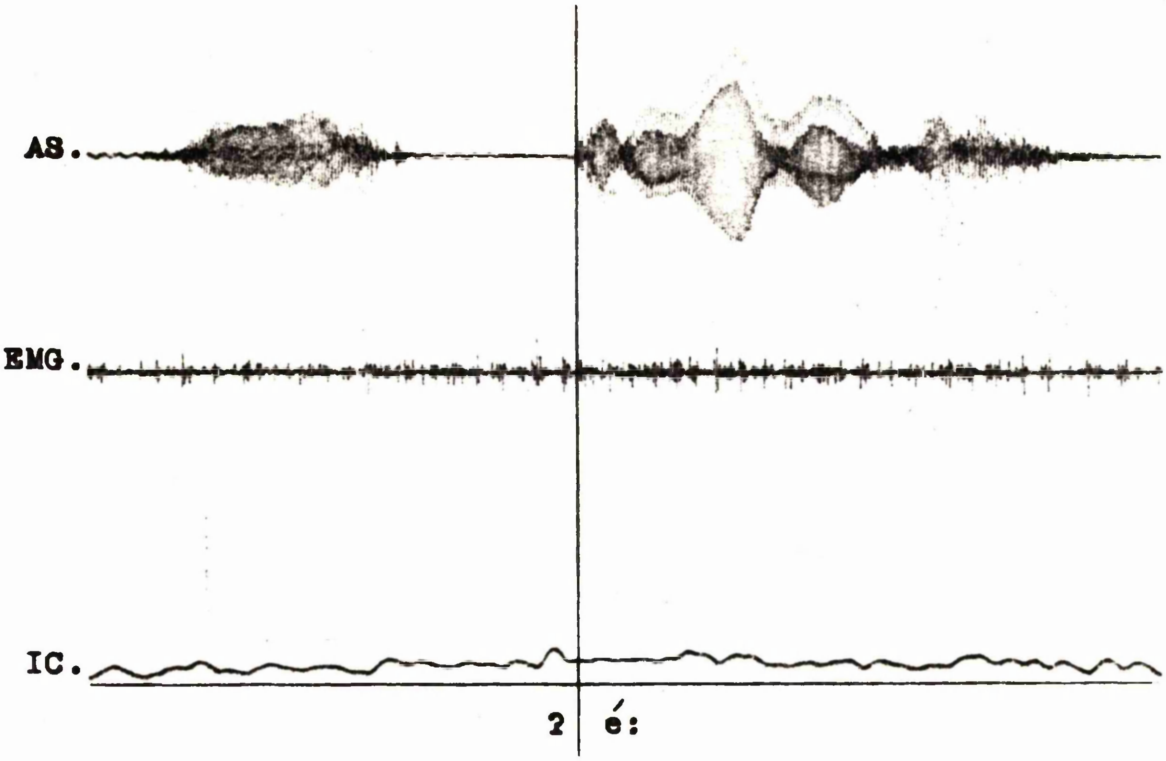


(a)

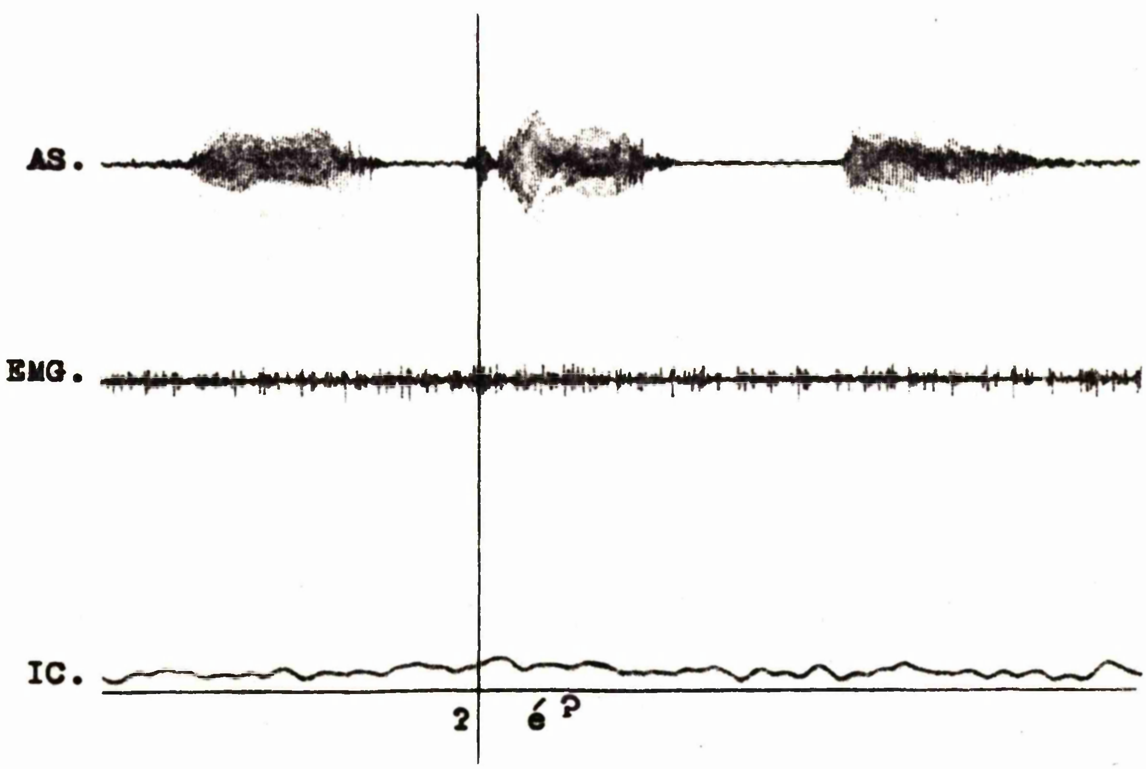


(b)

EMG IX

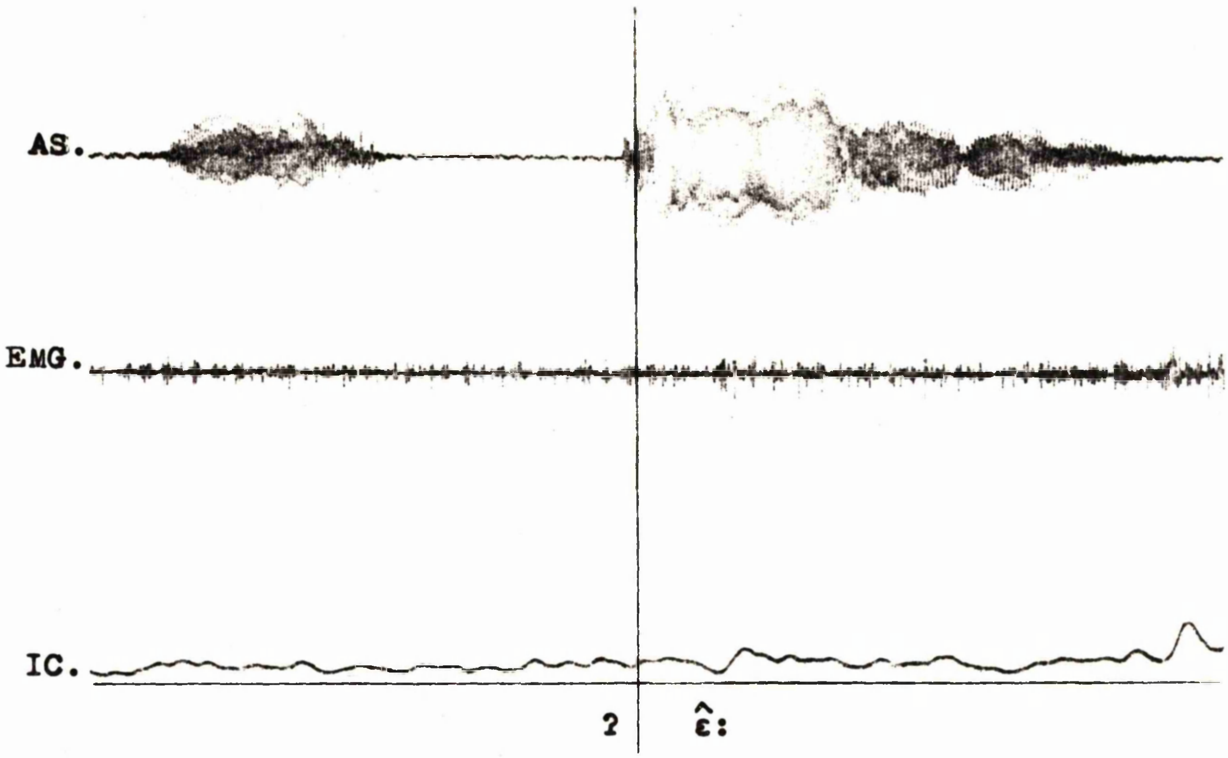


(a)

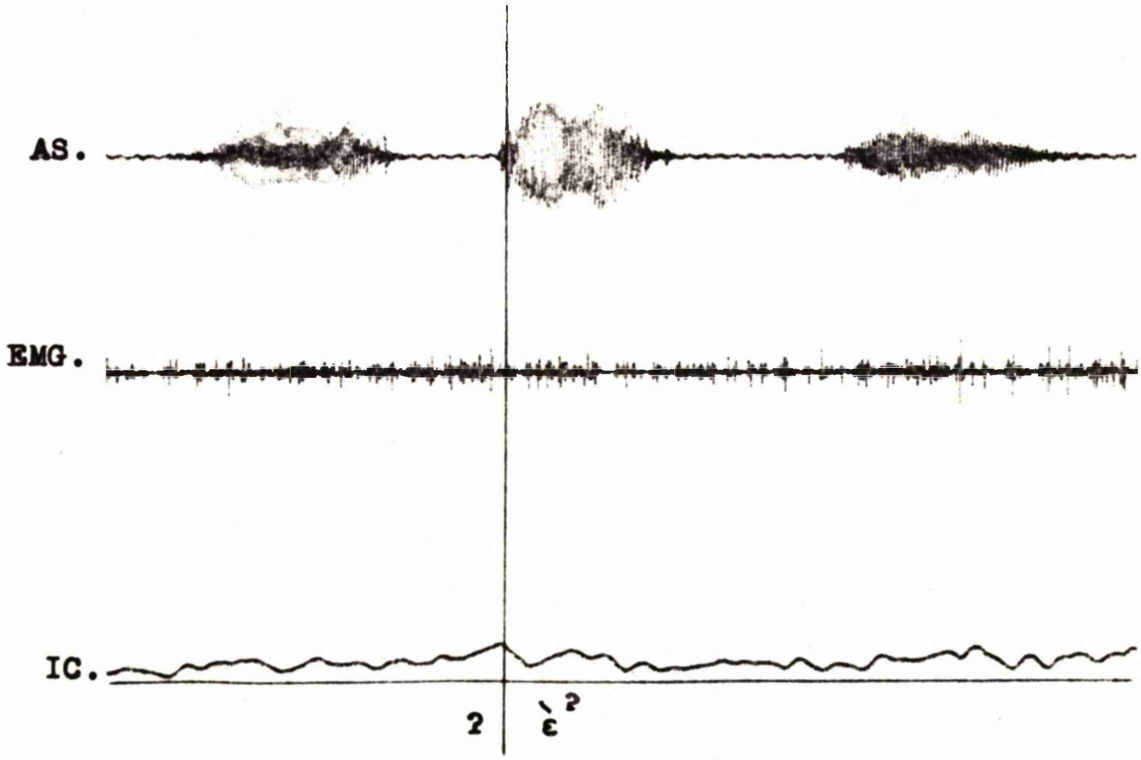


(b)

EMG X

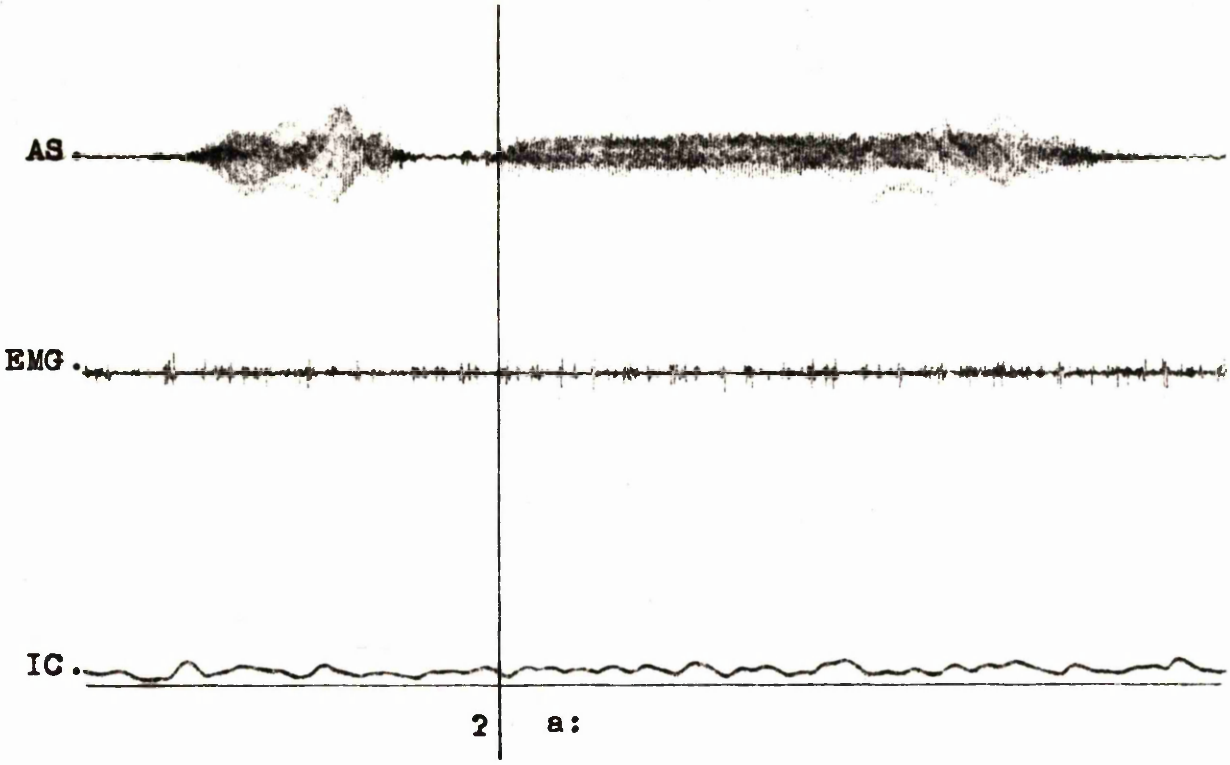


(a)

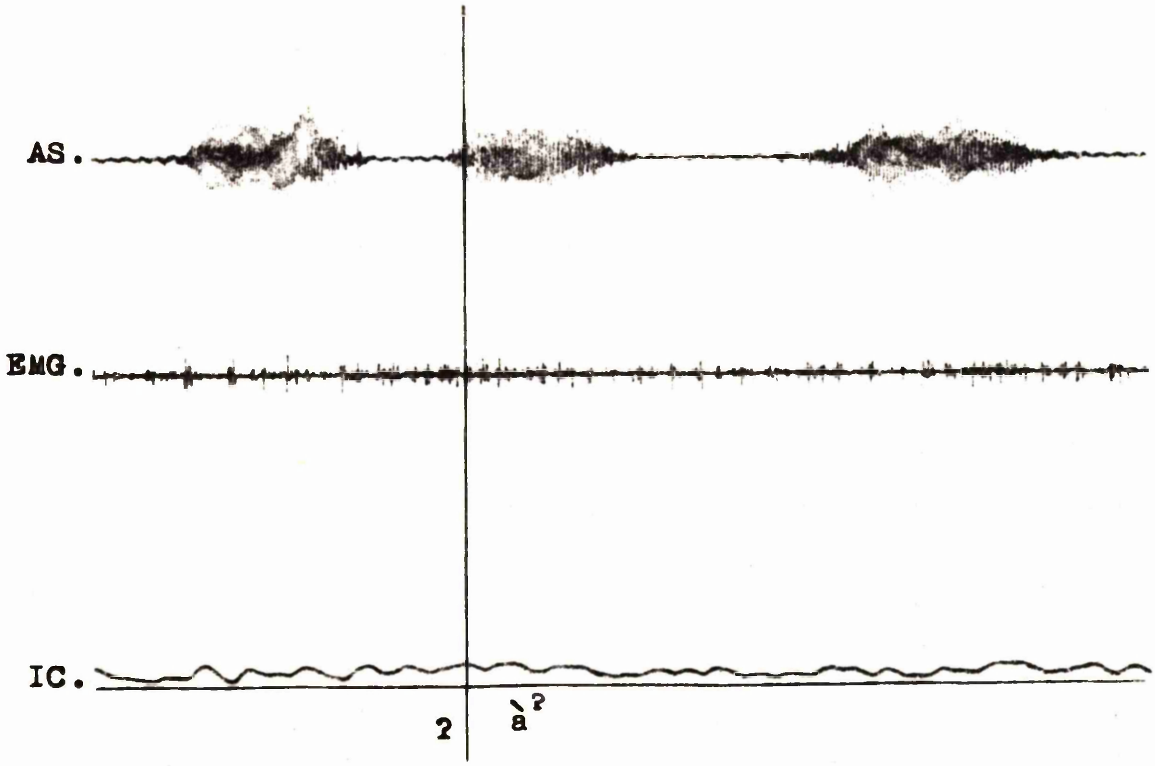


(b)

EMG XI

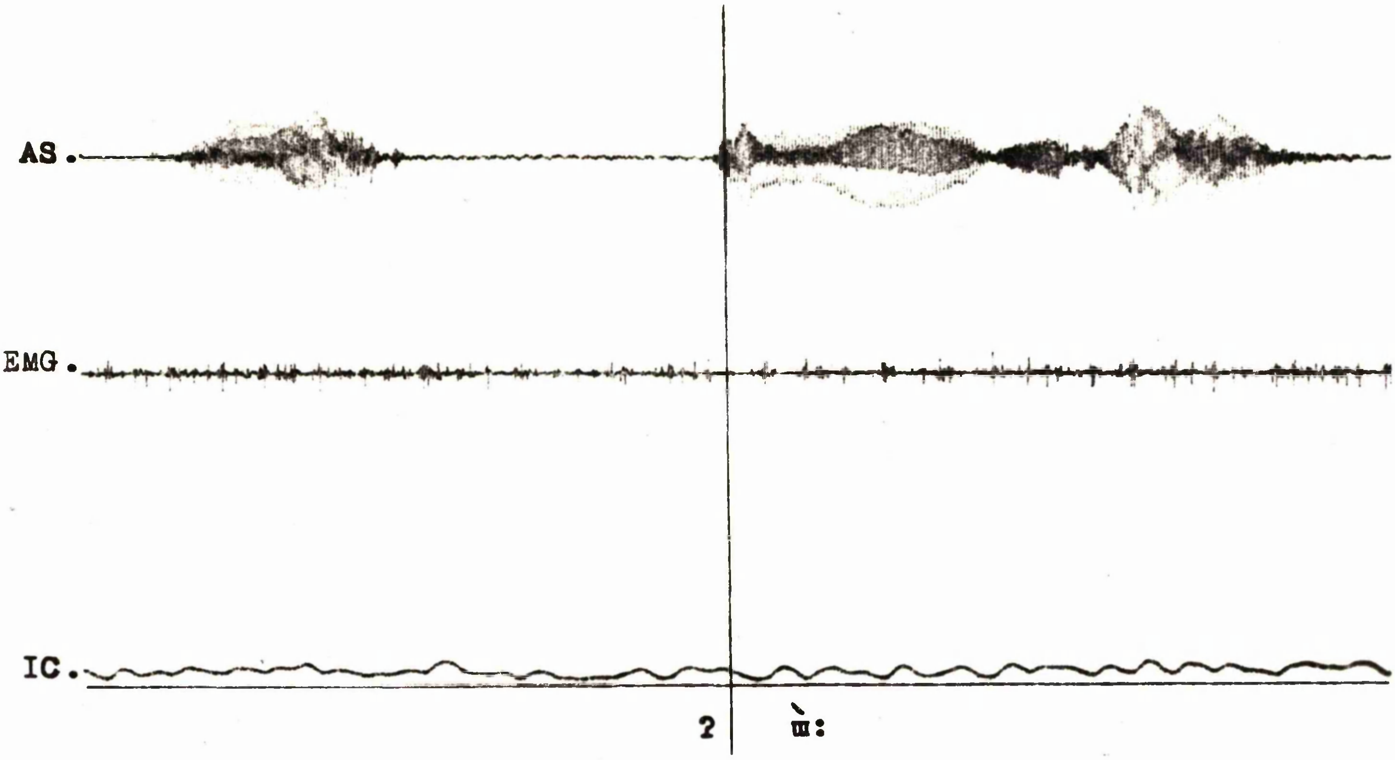


(a)

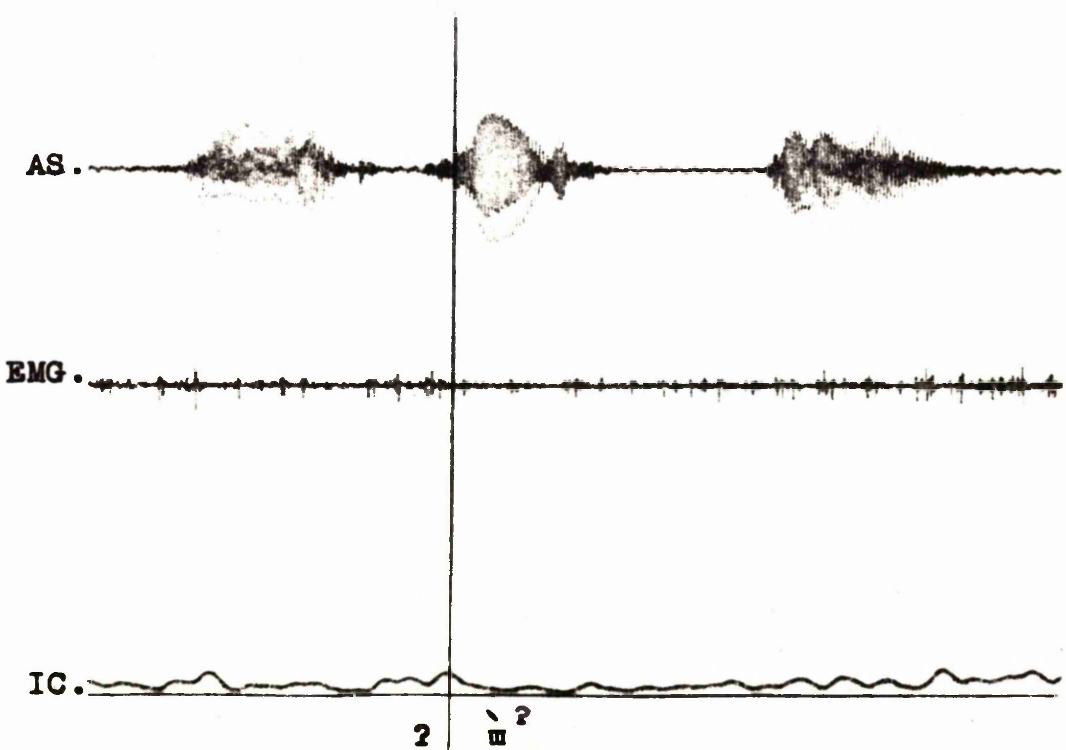


(b)

EMG XII

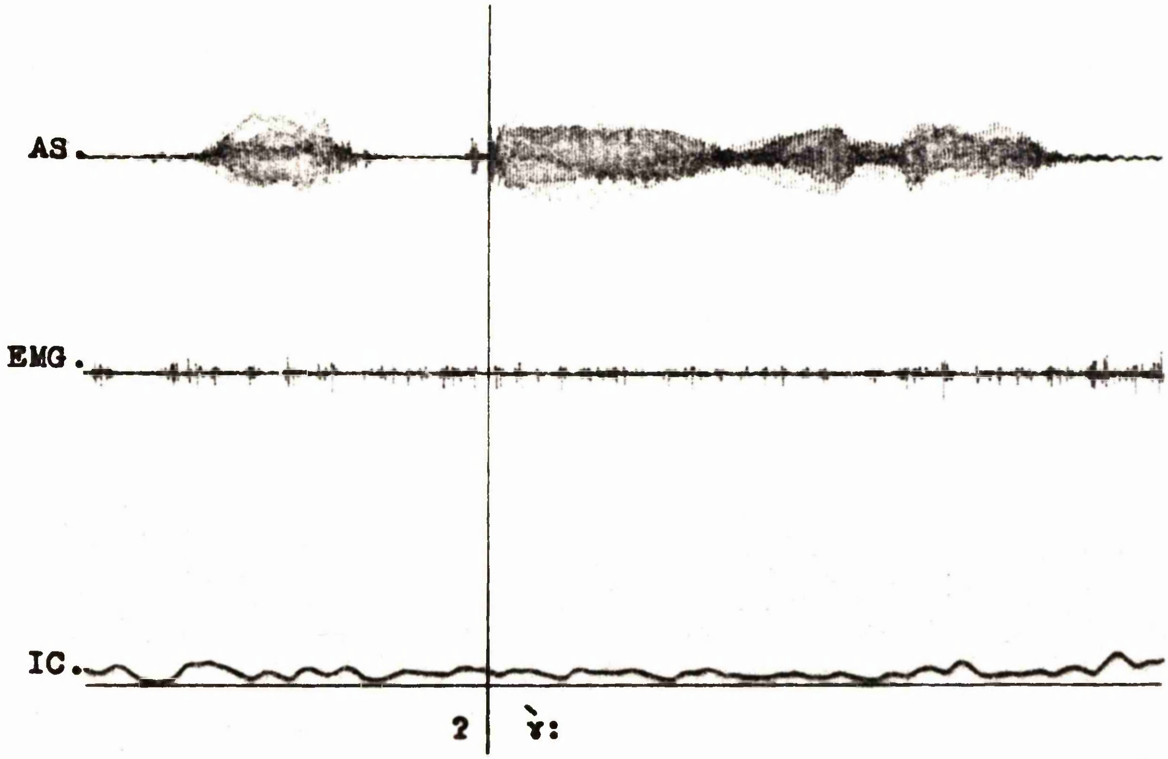


(a)



(b)

EMG $\overline{\text{XIII}}$



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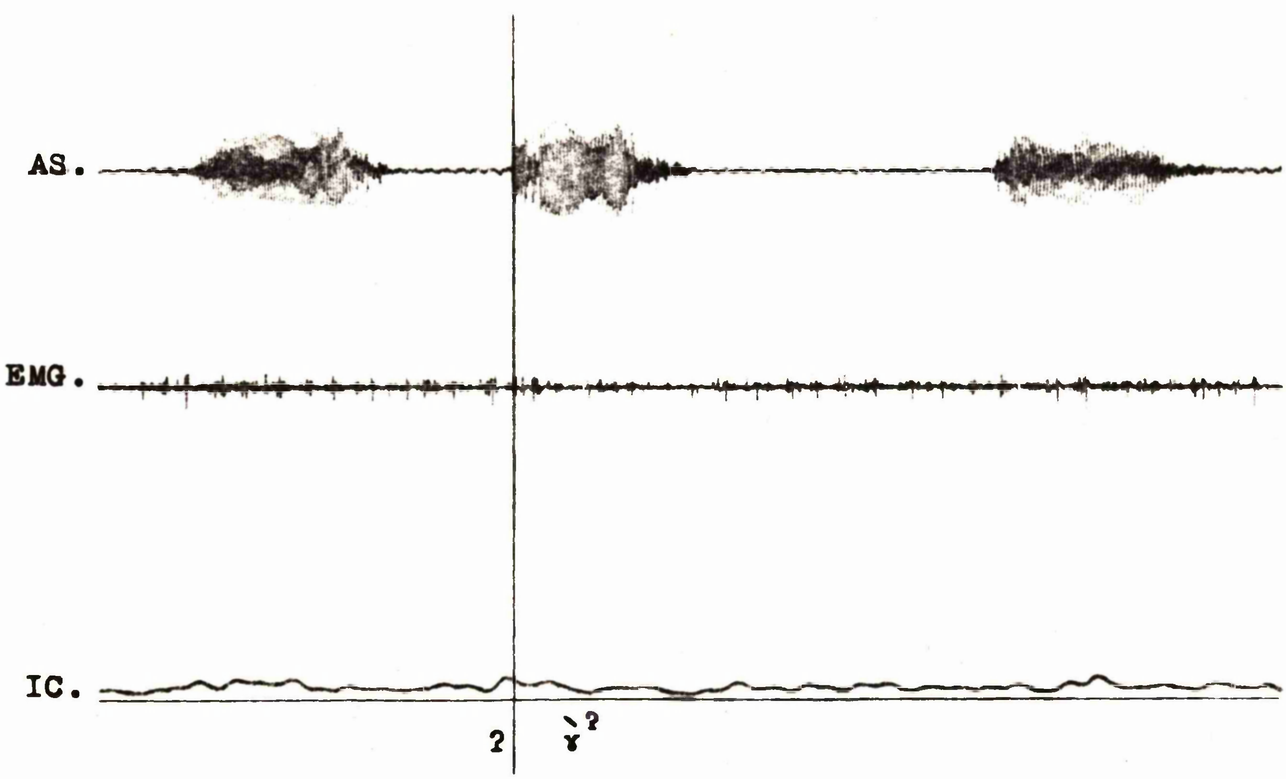

(b)

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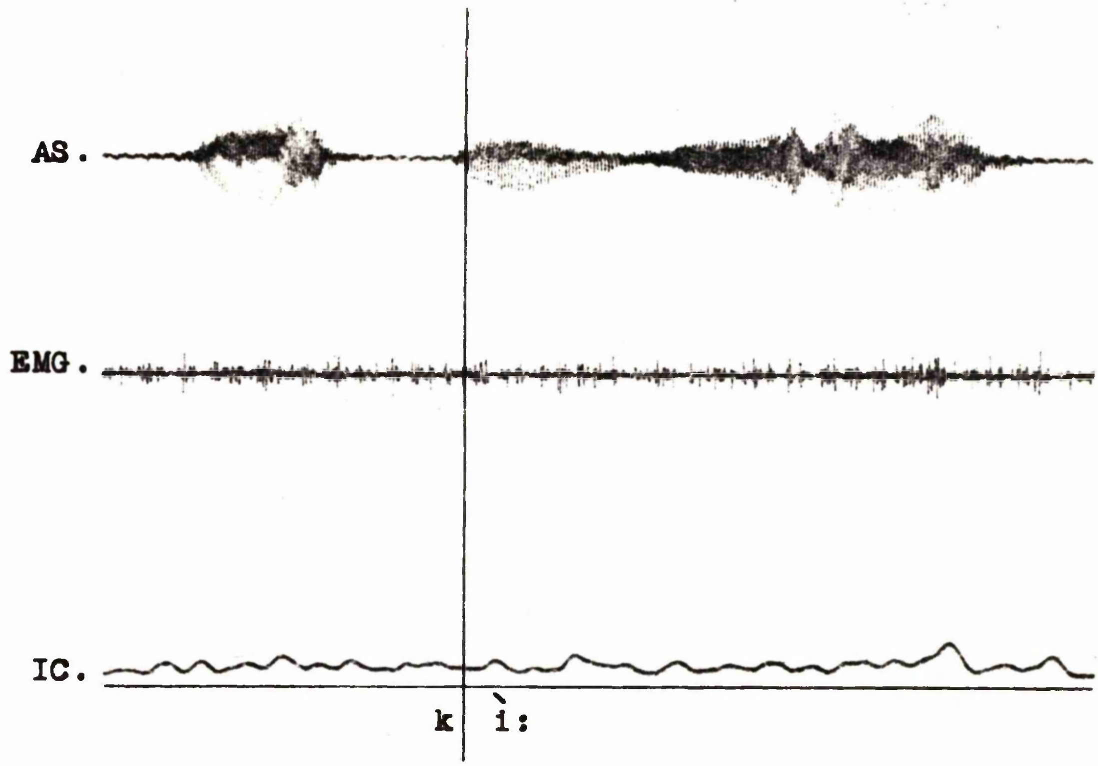

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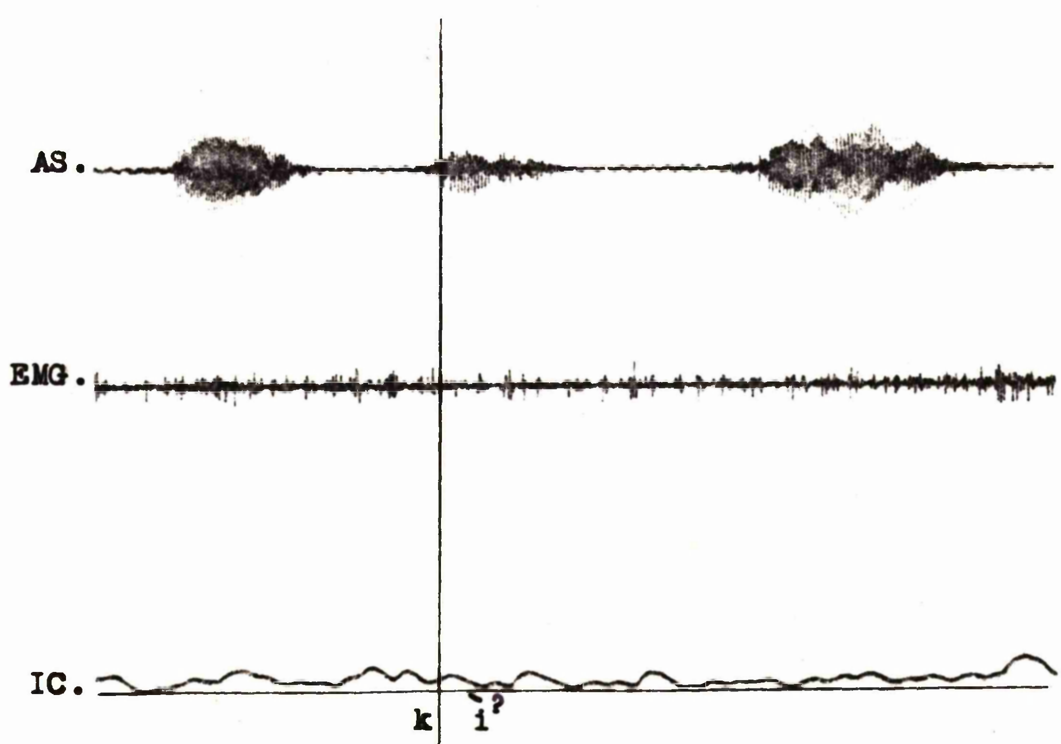

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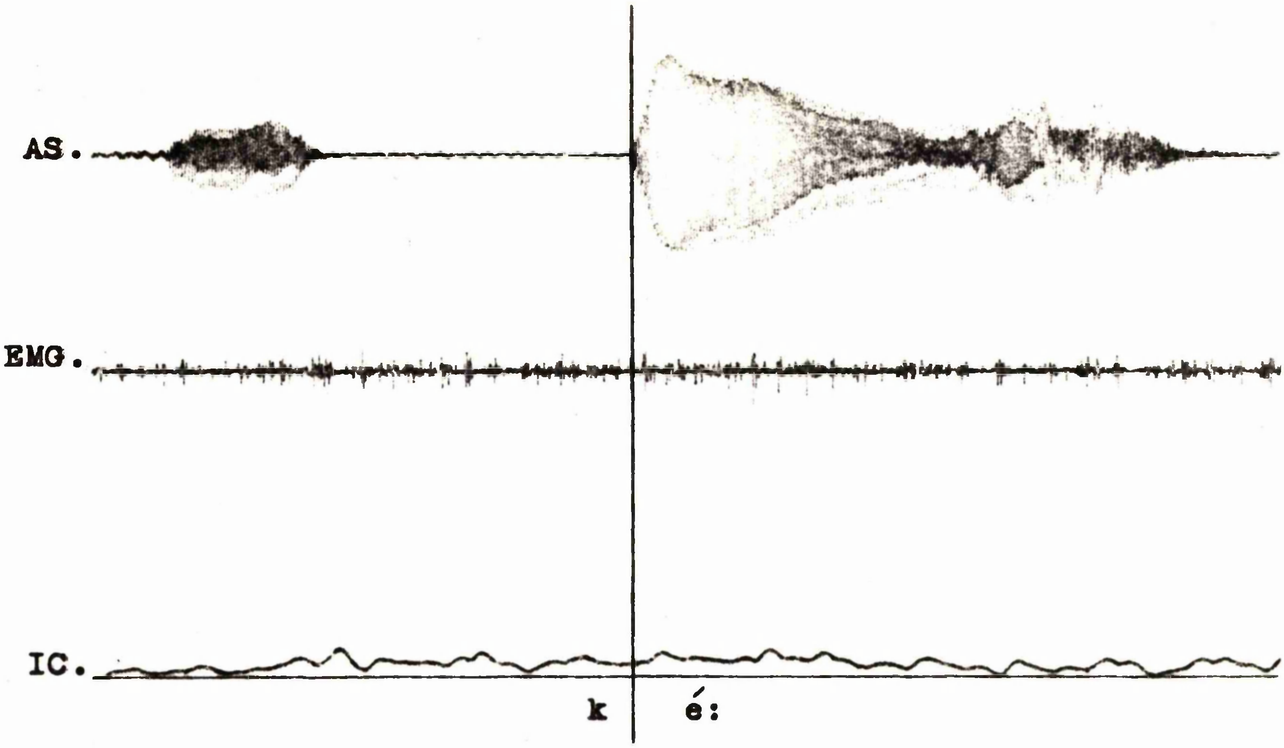
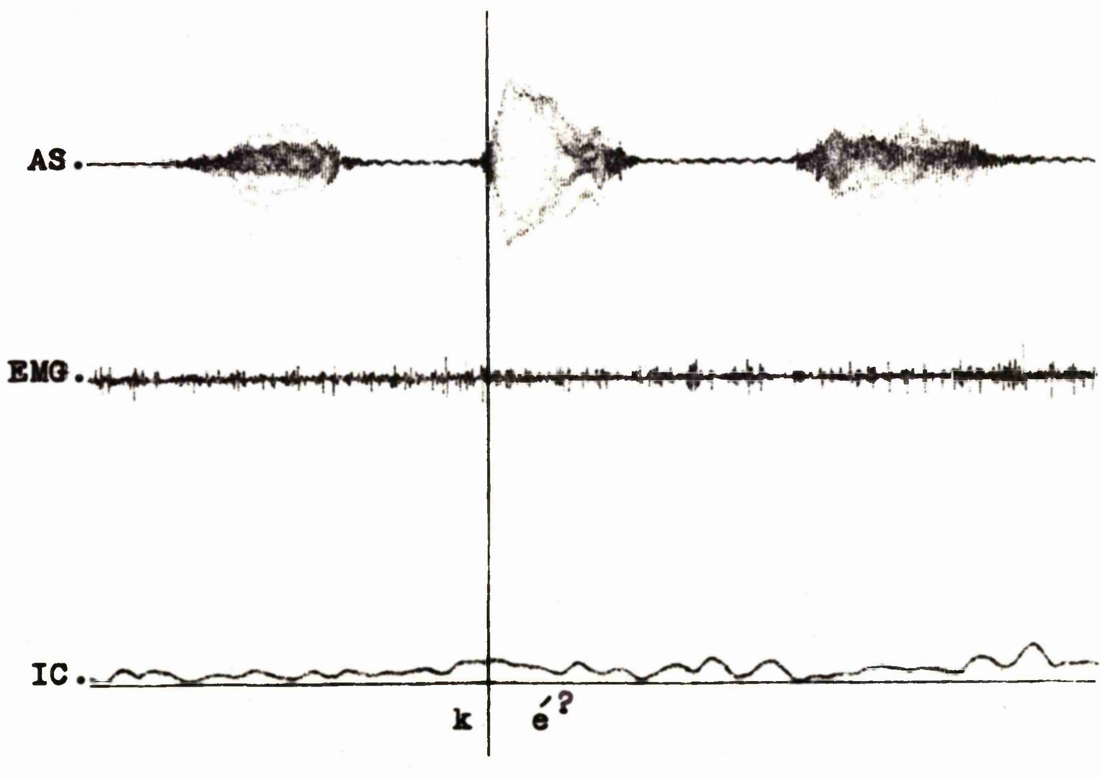
EMG XV

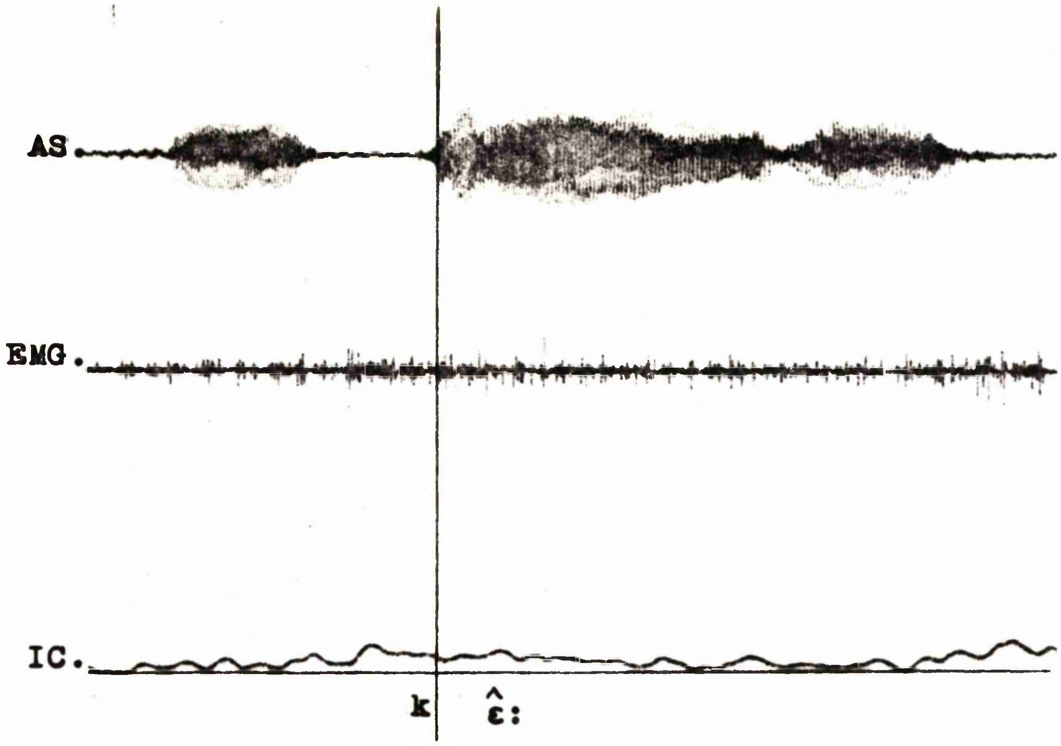


(a)

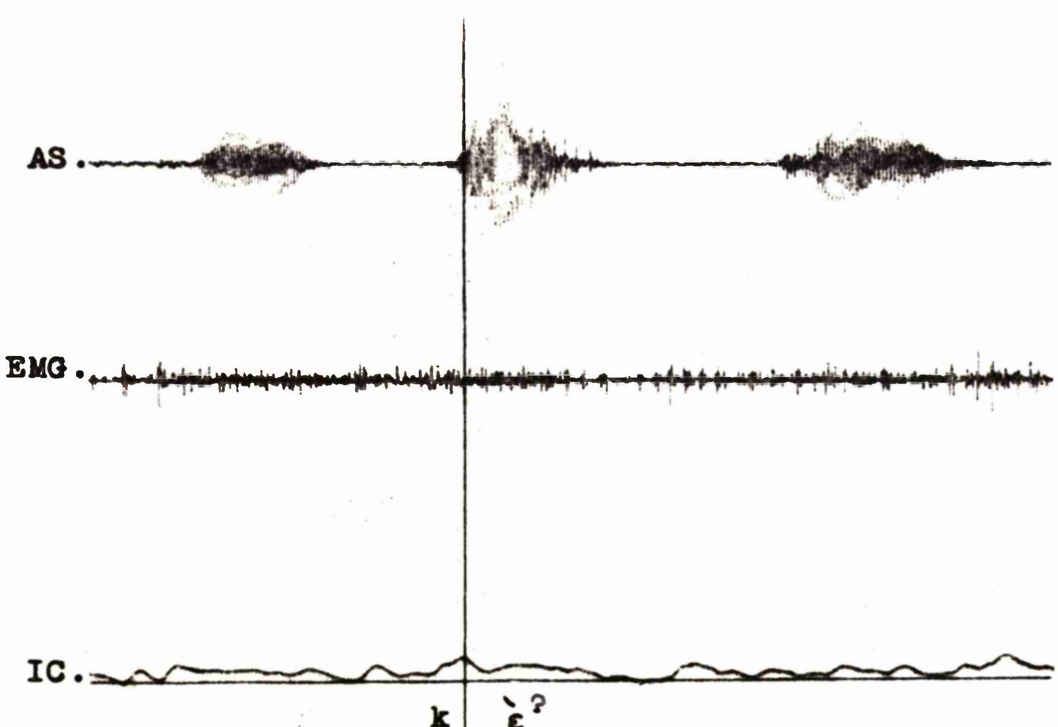


(b)

EMG XVI

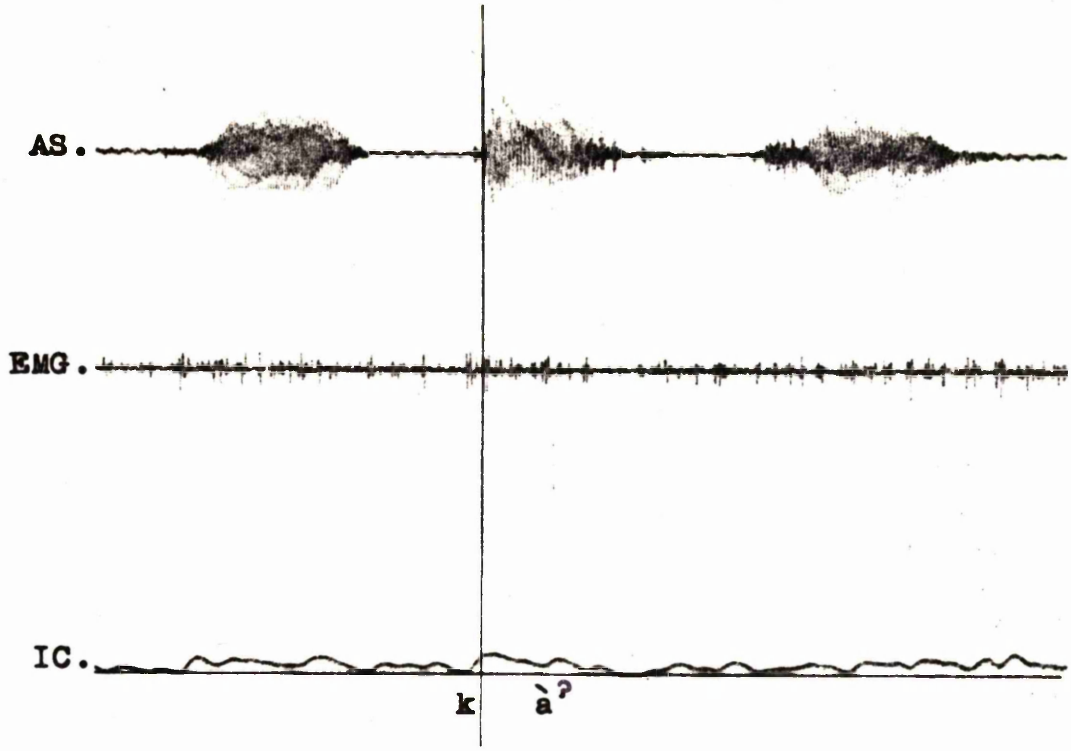


(a)

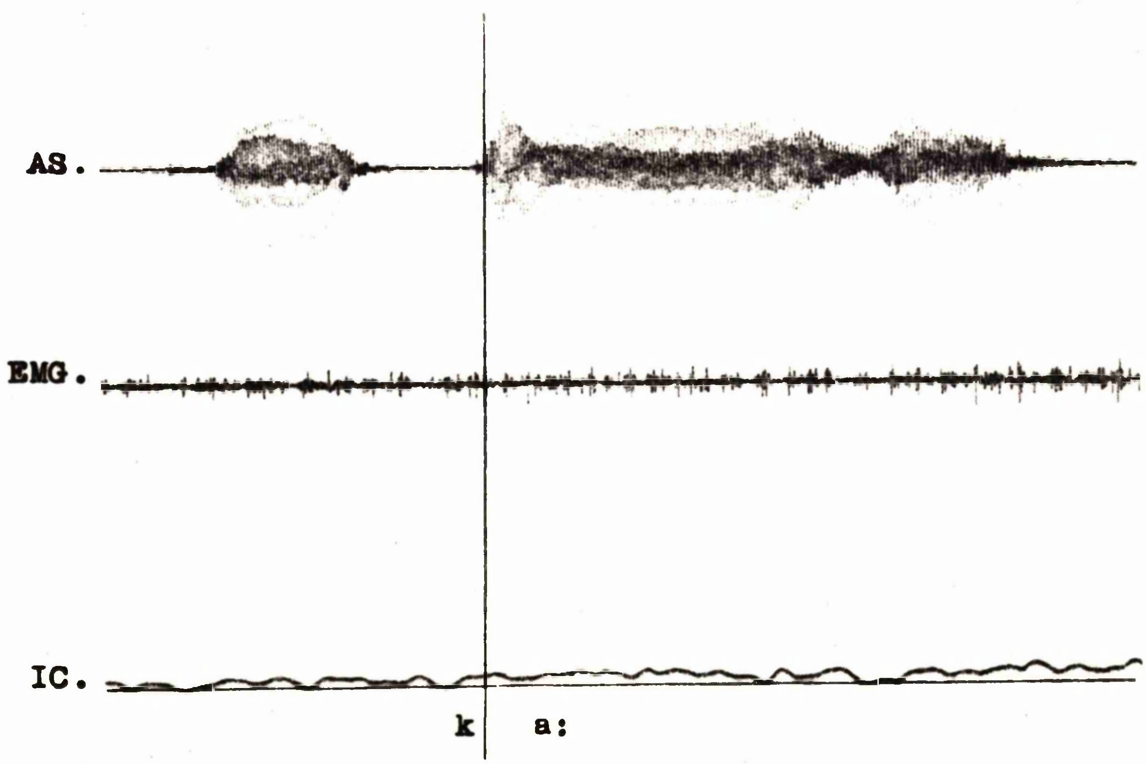


(b)

EMG XVII

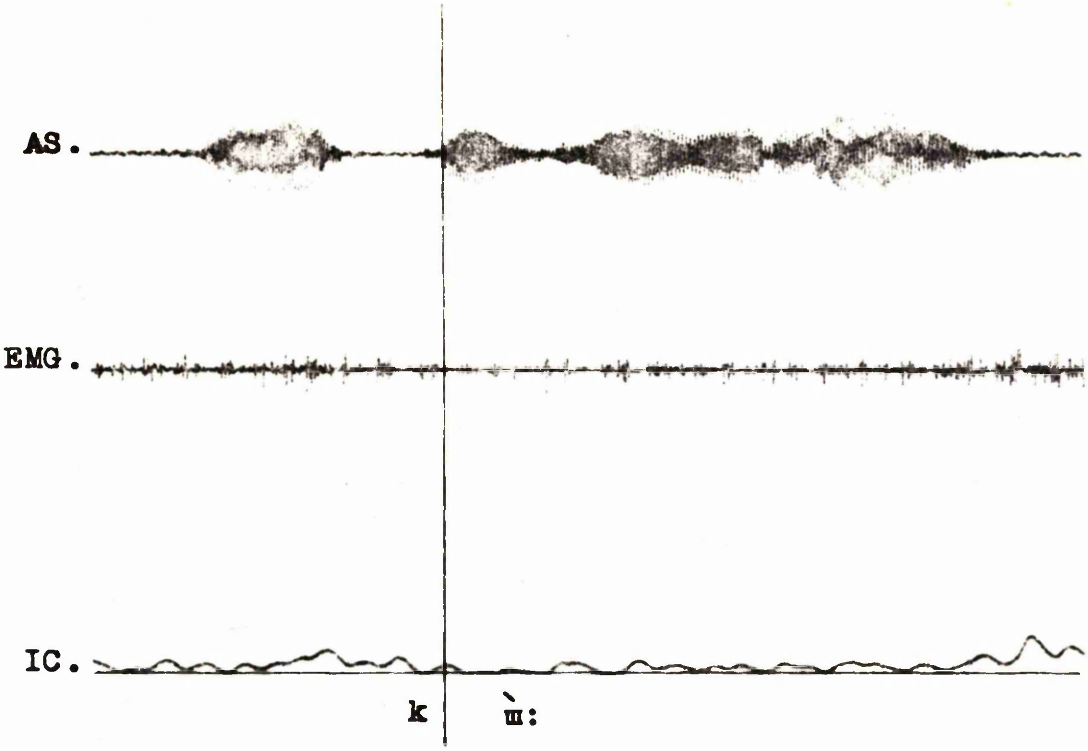


(a)

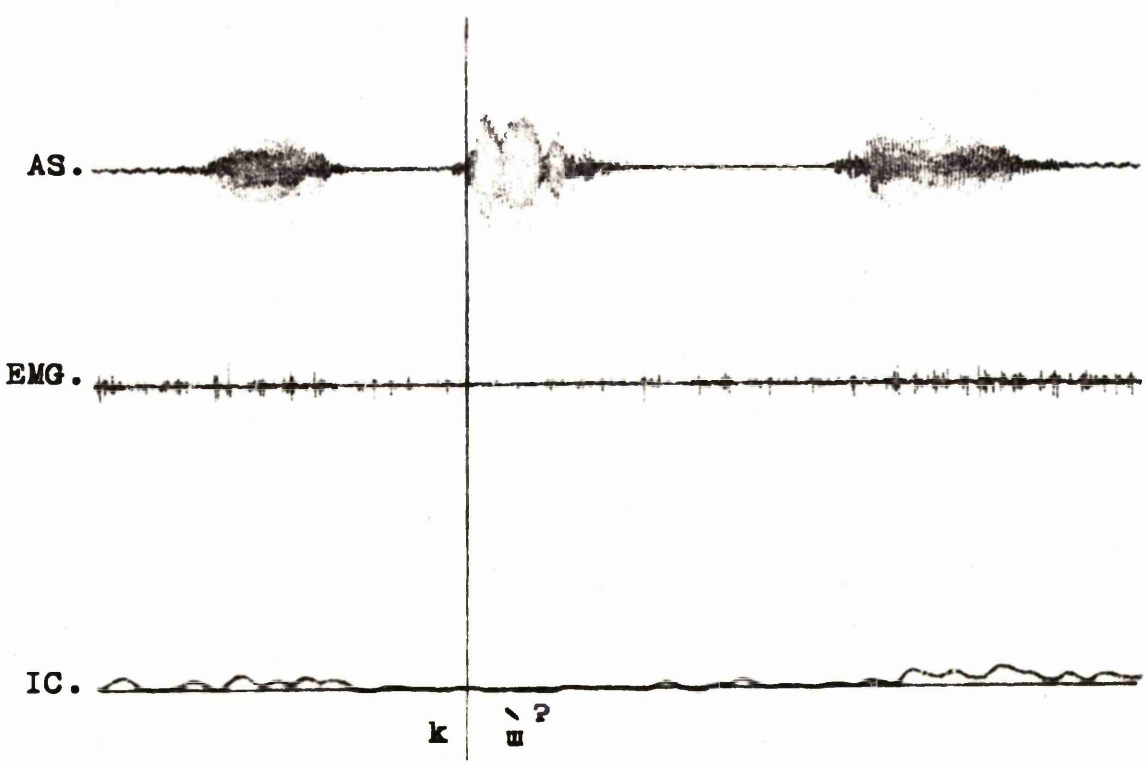


(b)

EMG XVIII

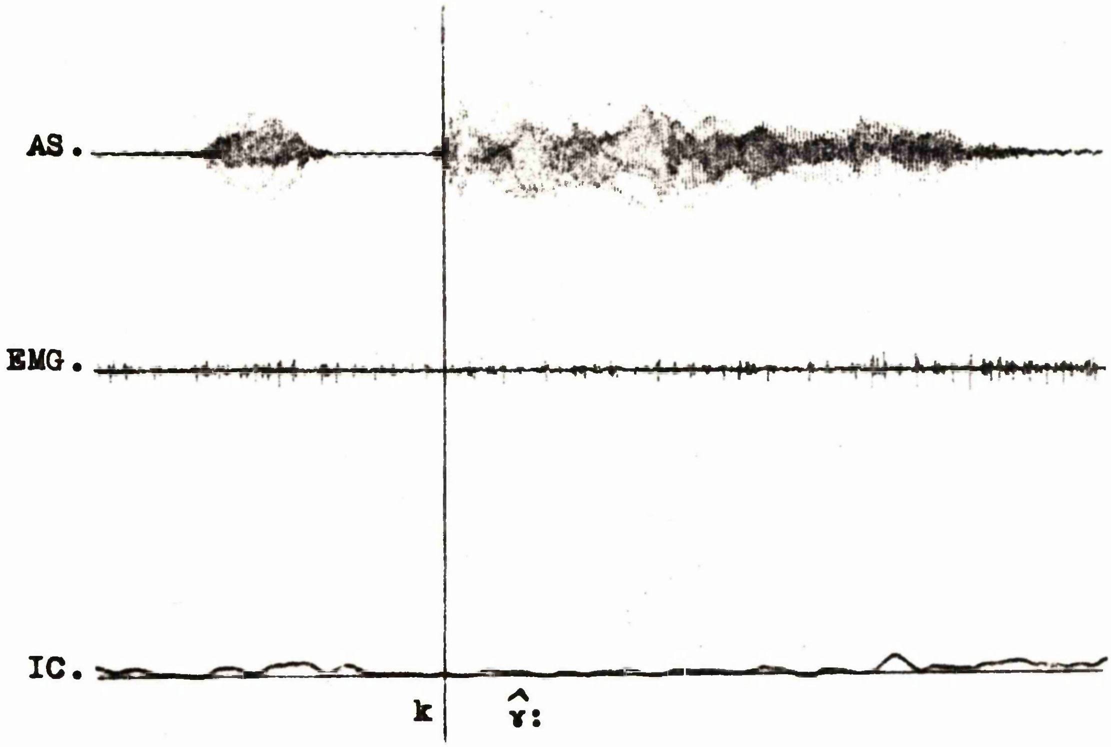


(a)

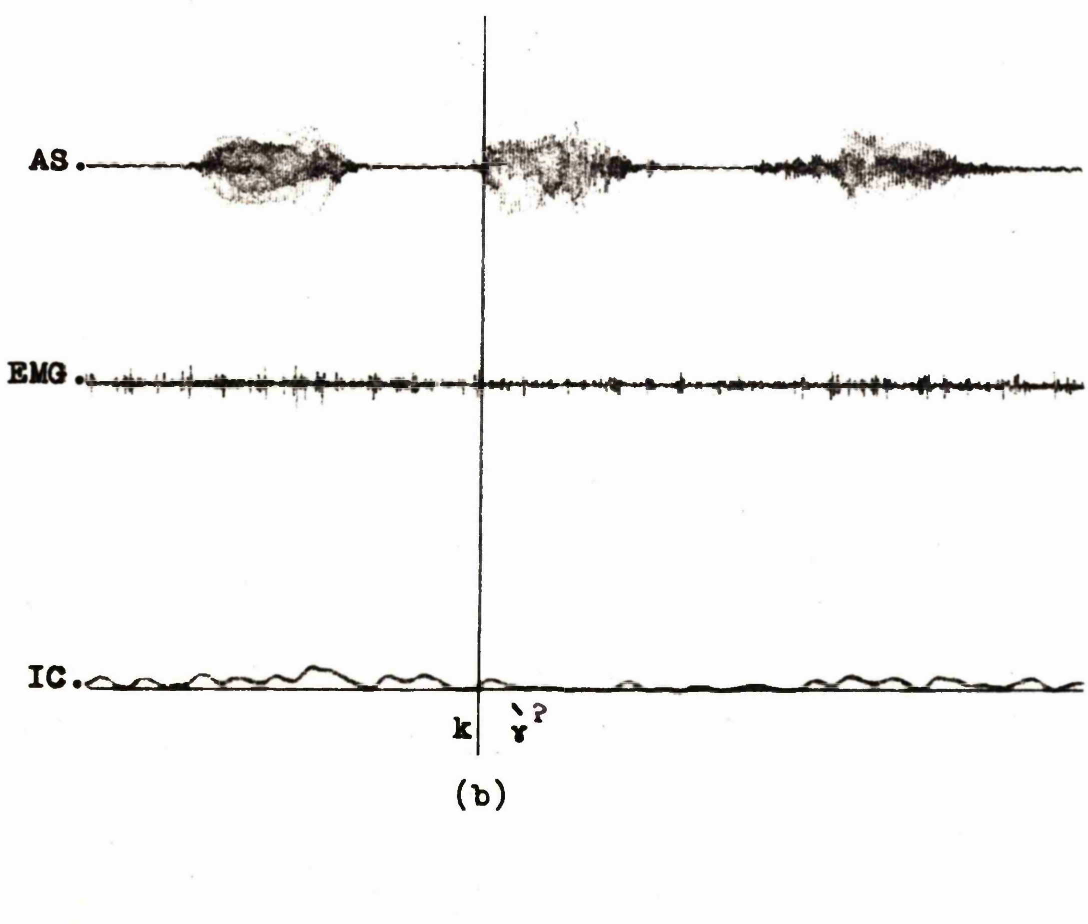


(b)

EMG XIX



(a)



(b)

Intensity dimension of rounded monophthongs.

From the electromyograms interesting phenomena of rounding are disclosed which go beyond what has been said in the traditional literature. According to the procedures mentioned earlier in the previous chapter 2, the characteristics of the intensity dimension of the OOI muscle employed in performing the rounding gestures were also qualitatively compared among the rounded vowels. The data is presented in averaged integrated curves in AIC I-III, and in difference curves (DC) I-II.

Comments on the averaged integrated curves and the difference curves.

The study of this dimension is concentrated upon the vertical phase of the electromyographic integrated curve. As appearing on the contours of the averaged integrated curves there are two characteristics, one is a plateau like curve type which occurred in the production of [u:], [u] and [o:]. That is, the tension still continues level after the onset of the acoustic signal. The other is a pyramid-like curve for [ɔ:] and [ɔ]; the tension declines immediately after the acoustic onset. The integrated curve of [o] seems to have transitional characteristic between the two differences. From the figures of the averaged integrated curves and difference curves it may be concluded that:

The curve for [u:] and [u] has relatively the same degree of intensity;

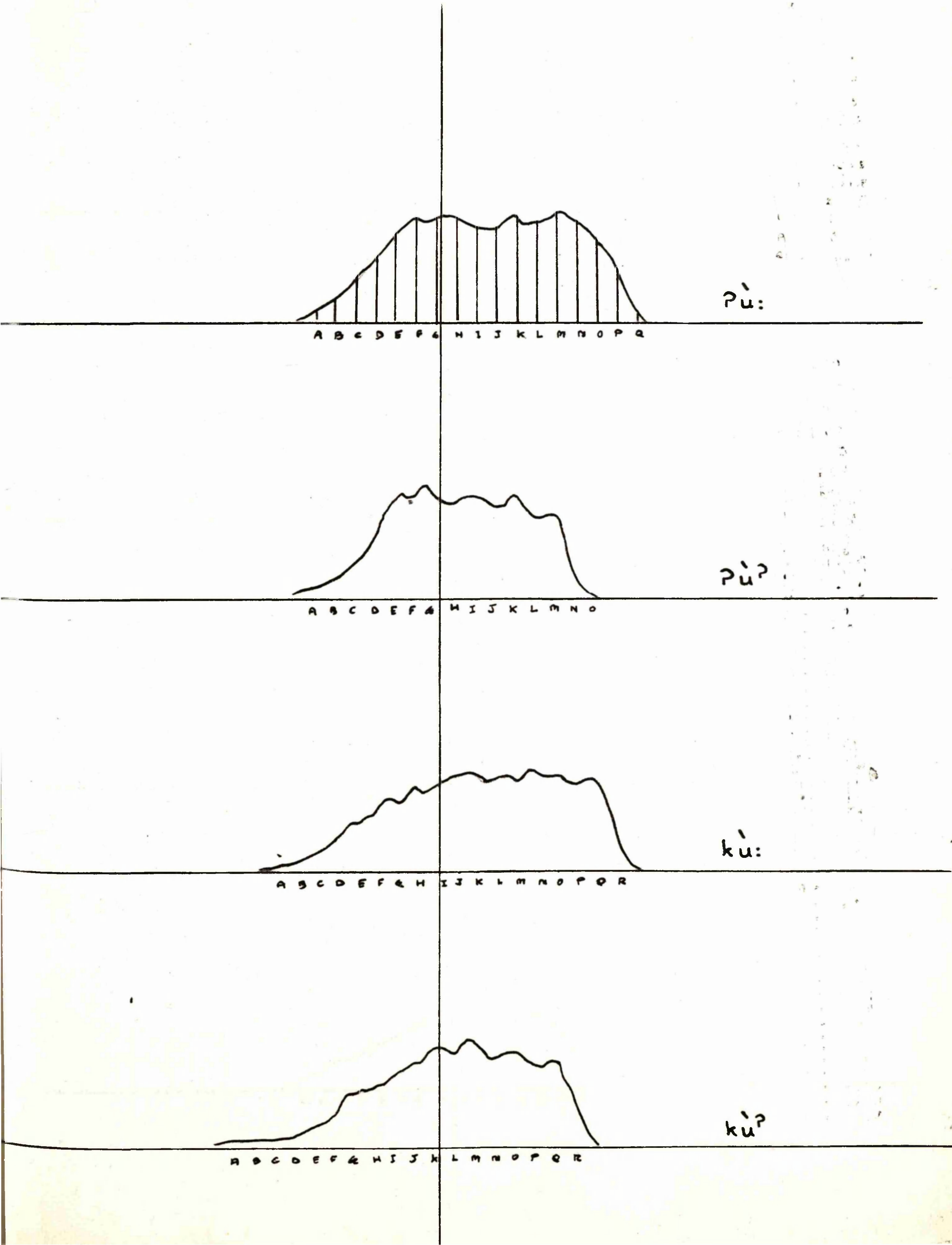
The curve for [u:] and [o:] also has the same degree of intensity;

The curve for [u:] and [o] reveals a distinction of intensity from those [u:] , [u], and [o:] ;

The curve for [u:] and [ɔ:] has relatively the same intensity as as that of [u:] and [o];

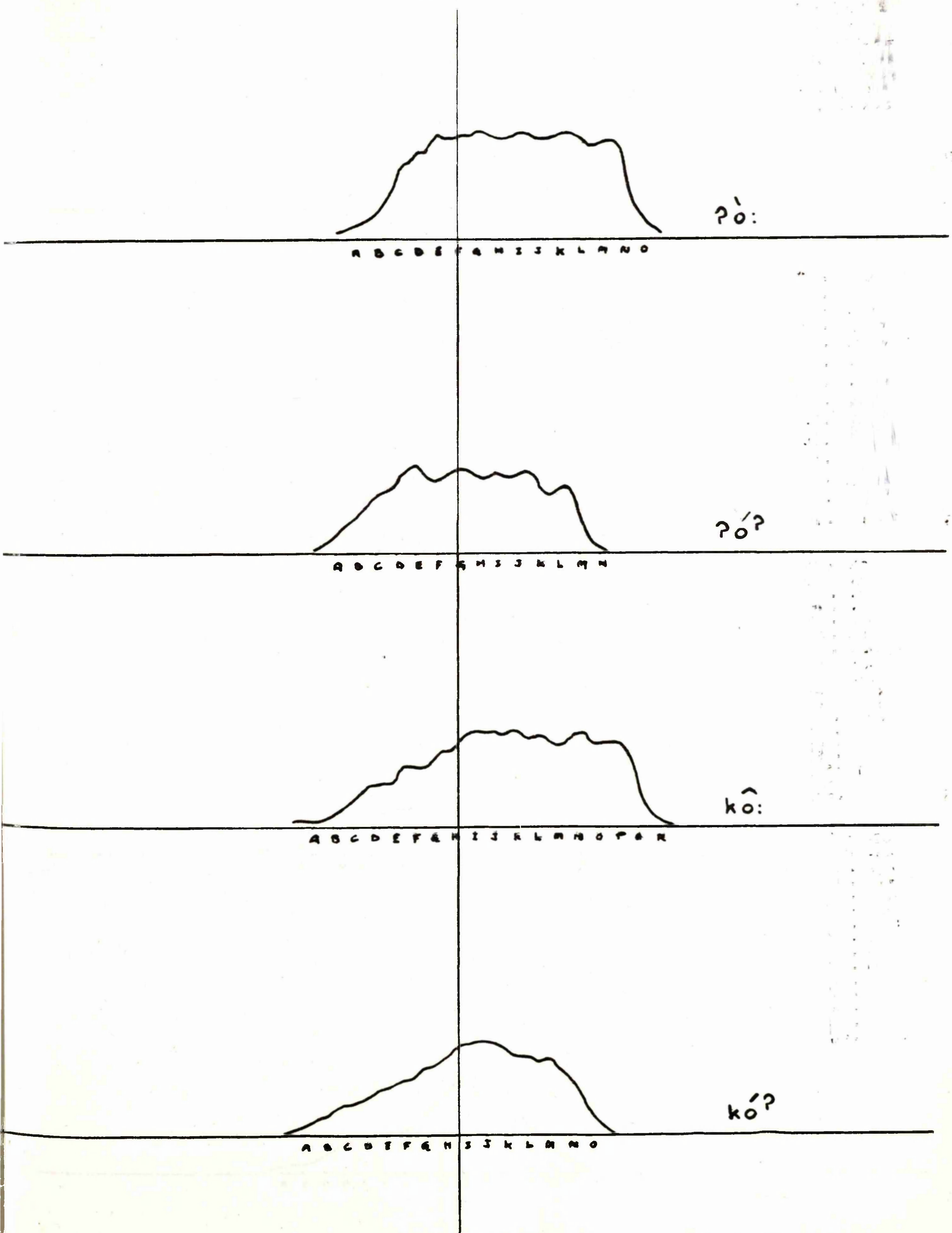
The curve for [u:] and [ɔ] has similar differences to those between [u:] and [o], and [u:] and [ɔ:].

AIC I

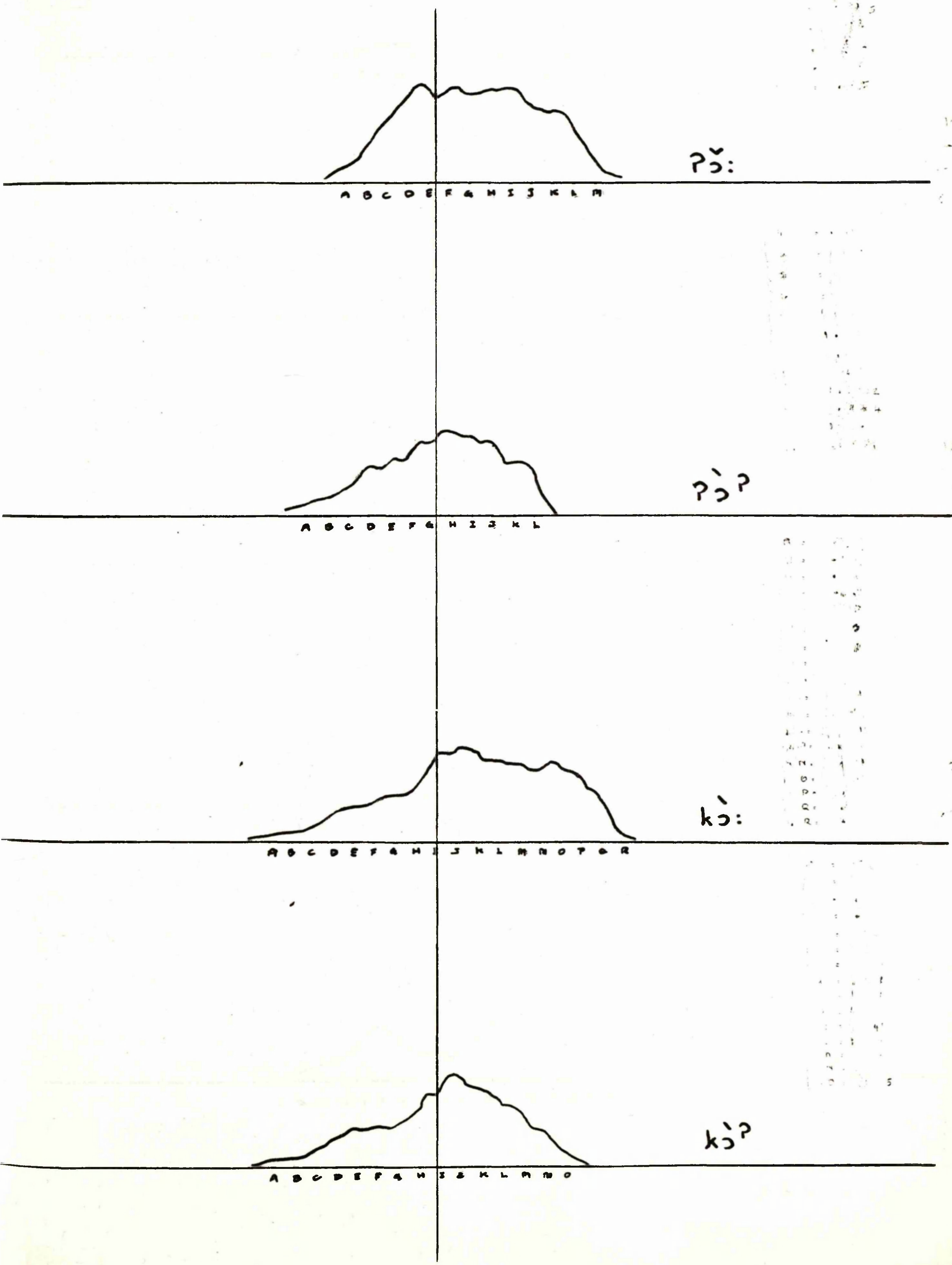


ʔù:
A B C D E F G H I J K L M N O P Q
ʔùʔ
A B C D E F G H I J K L M N O
kù:
A B C D E F G H I J K L M N O P Q R
kùʔ
A B C D E F G H I J K L M N O P Q R

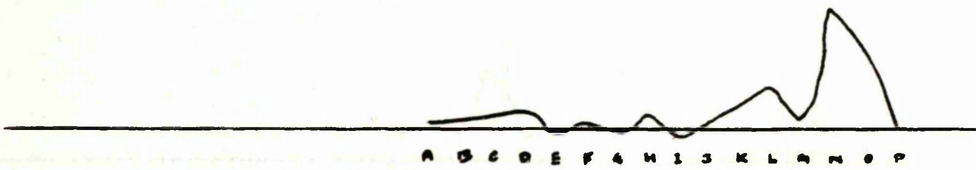
AIC II



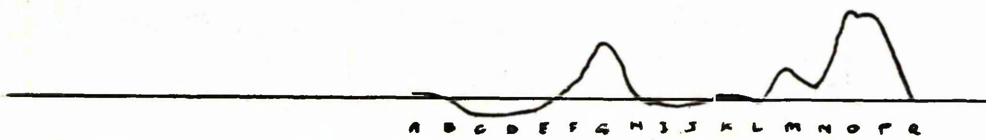
AIC III


ʔɔ̌:
A B C D E F G H I J K L M
ʔɔ̀ʔ
A B C D E F G H I J K L
kɔ̀:
A B C D E F G H I J K L M N O P Q R
kɔ̀ʔ
A B C D E F G H I J K L M N O

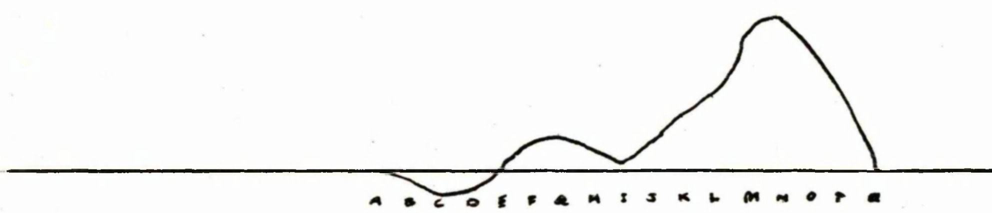
DC I



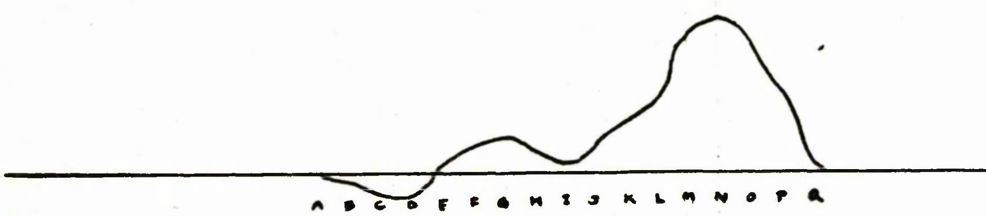
ʔù: ʔù?



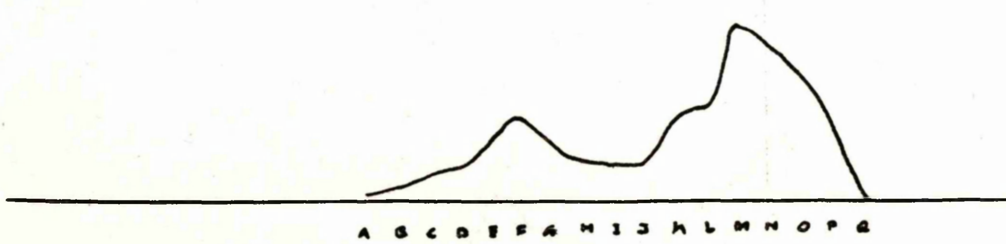
ʔù: ʔò:



ʔù: ʔó?

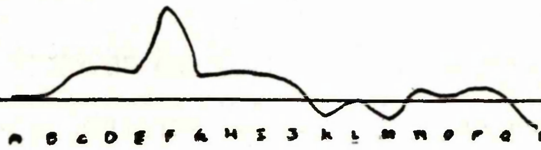


ʔù: ʔɔ̌:

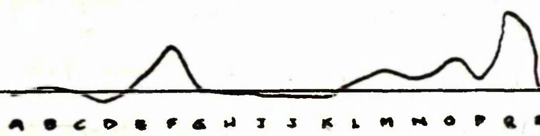


ʔù: ʔɔ̀?

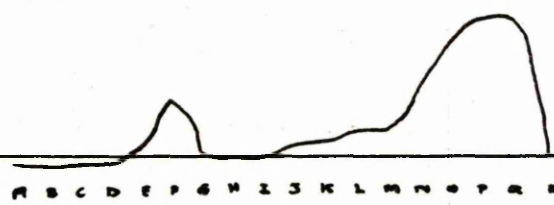
DC II



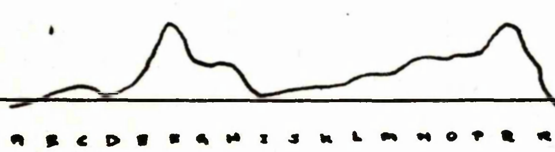
kù: kùʔ



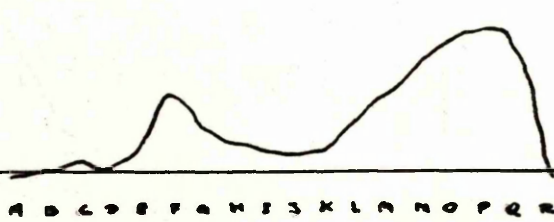
kù: kô:



kù: kóʔ



kù: kɔ̀:



kù: kɔ̀ʔ

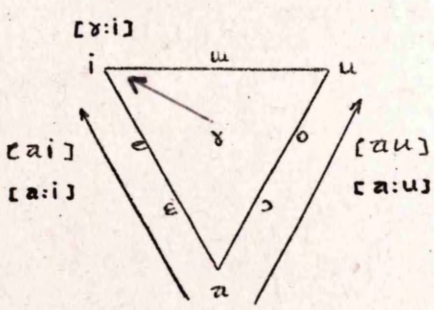
CHAPTER 5

THE STUDY OF ORBICULARIS ORIS INFERIORIS (OOI) MUSCLE ACTIVITY IN DIPHTHONGS AND TRIPHTHONGS

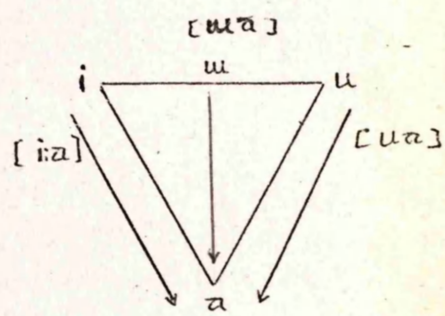
General introduction.

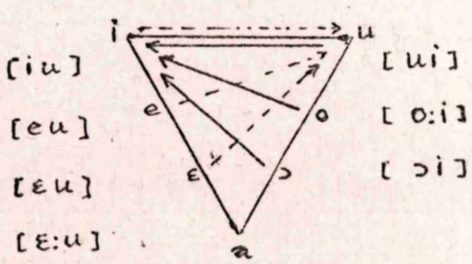
Diphthongs in Standard Thai are classified into two categories namely: closing diphthongs for those composed of front vowels gliding towards the high-back-rounded vowel, or of back vowels (including unrounded [ɤ]) gliding towards the high front unrounded vowel, and the [a] gliding upwards in the directions of the high-front and the high-back. The other group is opening diphthongs which have the high-front and the high-back gliding downwards to the [a]. The diagrams suggested by Henderson (1975: 263) are practical in illustrating the phonological pattern of the diphthongs.

closing diphthongs



opening diphthongs





Accordingly, those closing and the opening diphthongs which which initiated by the rounding gestures, their phonetic representations are: [ui], [o:i], [ɔi] and [ua] respectively; the measurements: intitial rounding anticipation for these diphthongs are presented in Table 3, The measuremensts of the closing diphthongs which ended by rounding gesture: [iu], [eu], [ɛu], [ɛ:u].

In this study only diphthongs containing a unrounded vowel as one of these elements will be dealt with, i.e. [ai], [a:i], [i:a], [ɯa] and [ɤ:i] are excluded.

OOI muscle activity for diphthongs.

Time dimension:

Time onset of the syllables initially containing rounded vowels, in msec.

Table 3 Initial rounding anticipation in diphthongs starting with rounded vowels (five utterances)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	230		1	280
	2	240		2	405
	3	305		3	240
ʔúi	4	470	kúi	4	280
	5	190		5	278
	average	287		average	297
	SD	98.67		SD	56.30
	1	220		1	223
	2	190		2	260
	3	180		3	284
ʔɔːi	4	215	kɔːi	4	240
	5	248		5	260
	average	211		average	253
	SD	23.94		SD	20.63
	1	100		1	240
	2	200		2	367
	3	190		3	266
ʔɔ̌i	4	210	kɔ̂i	4	180
	5	154		5	196
	average	171		average	250
	SD	40.13		SD	66.12
	1	375		1	350
	2	230		2	190
	3	230		3	210
ʔúa	4	235	kua	4	164
	5	350		5	270
	average	284		average	237
	SD	64.60		SD	66.52

PT = Phonetic Transcription
Ao = Audio onset

<u>Table 4a</u> Final rounding anticipation and time-lag in diphthongs ending with rounding gesture (five utterances)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	55		1	40
	2	-18		2	40
	3	-44		3	-10
ʔíu	4	45	kíu	4	-30
	5	-25		5	-30
	average	2.6		average	2
	SD	39.75		SD	20.98
	1	25		1	-107
	2	10		2	-110
	3	-30		3	- 93
	4	-20		4	- 70
ʔeu	5	-62	keu	5	-100
	average	-15.4		average	-96
	SD	75.05		SD	14.27

<u>Table 4b</u> Final rounding time-lag in diphthongs ending with rounding gesture (five utterances)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
PT	1	-30		1	-160
	2	-15		2	-180
	3	-30		3	-220
ʔɛ̌u	4	-20	kɛ̂ːu	4	-210
	5	-18		5	-245
	average	-22.6		average	-203
	SD	6.25		SD	29.93
PT	1	-85		1	-60
	2	-115		2	-110
	3	-165		3	-135
	4	-80		4	-155
ʔau	5	-88	kau	5	-120
	average	-106.6		average	-116
	SD	31.62		SD	31.84

PT = Phonetic Transcription
Ao = Audio onset
- mark indicates EMG onset begins after Audio onset.

Comments on Tables 3, 4a and 4b.

The patterns of time onset on Table 3 are the same as those found in the production of monophthongs. That is, the more rounded vowels have longer anticipation than the less rounded ones. This was found in both the syllables preceded by [ʔ] and [k].

For the other group in Table 4a and 4b, the closing diphthongs ending with rounding gesture, the phonetic representations are : [iu], [eu], [ɛ:u], [ɛu] and [au]. There are two characteristics of the time onset here. For the [ʔíu] and the [kìu] the time onset of the rounding starts prior to the acoustic signal. On the other hand, in [ʔeu], [ʔɛ̌u], [ʔau], [keu], [kɛ̂:u] and [kau], the rounding is delayed until after the onset of the acoustic signal. These may be explained that [iu] possesses more initial closing gesture than [eu], [ɛu], [ɛ: u], and [au]. Thus the rounding gesture in [iu] always started earlier than that in [eu], [ɛu], [ɛ:u] and [au].

Time dimension of the OOI muscle activity for diphthongs.

Duration (in msec.)

In the closing diphthongs ending with spreading gesture: [ui], [o:i] and [ɔi], and the opening diphthongs [ʔúa], and [kua] the durations of the rounding gestures vary according to the functional length of the roundings (see Table5). It also appeared that the SD of [ʔúi] is extremely high. This may be the effect of the high variation in rounding anticipation of this syllable. However, the SD figures of the syllables initiated by rounding gesture look in generally high. The evidence may be explained that the OOI muscle is activated rather early when there is no preceding rounding performance in those syllables. That is, the OOI does not involve in the articulation of either [?] or [k], so that the muscle is free to move whenever the motor command for rounding arrives.

For the closing diphthongs ending with lip rounding posture, the durational period of the rounding is influenced by the length to the preceding elements. This is evident in [ʔɛ̌u] and [kɛ̂ːu] utterances (see Table 6).

Table 5 OOI muscle activity duration for diphthongs with initial rounding (five utterances).

PT	utterance order	EMG duration	PT	utterance order	EMG duration
	1	300		1	348
	2	334		2	480
	3	390		3	385
?úi	4	610	kúi	4	434
	5	343		5	400
	average	395.4		average	409
	SD	111.08		SD	44.82
	1	450		1	460
	2	415		2	530
	3	420		3	575
?o:i	4	434	ko:i	4	477
	5	486		5	535
	average	441		average	515
	SD	25.58		SD	41.70
	1	150		1	400
	2	255		2	520
	3	240		3	462
?ɔ̌i	4	335	kɔ̂i	4	260
	5	250		5	350
	average	246		average	398
	SD	58.77		SD	89.81
	1	530		1	545
	2	385		2	370
	3	360		3	400
?úa	4	400	kua	4	398
	5	540		5	490
	average	443		average	440
	SD	76.26		SD	66.01

Table 6 OOI muscle activity duration for diphthongs with final rounding gesture (five utterances).

PT	utterance ordern	EMG duration	PT	utterance order	EMG duration
	1	368		1	370
	2	325		2	374
	3	280		3	365
ʔíu	4	390	kìu	4	375
	5	285		5	355
	average	330		average	368
	SD	43.80		SD	7.30
	1	285		1	235
	2	350		2	290
	3	330		3	310
	4	370		4	340
ʔeu	5	295	keu	5	300
	average	326		average	295
	SD	32.16		SD	34.35
	1	320		1	175
	2	290		2	170
	3	285		3	200
ʔɛ̌u	4	332	kɛ̂:u	4	180
	5	335		5	215
	average	312		average	188
	SD	21		SD	16.91
	1	280		1	310
	2	275		2	285
	3	270		3	290
	4	270		4	240
ʔau	5	320	kau	5	270
	average	283		average	279
	SD	18.87		SD	23.32

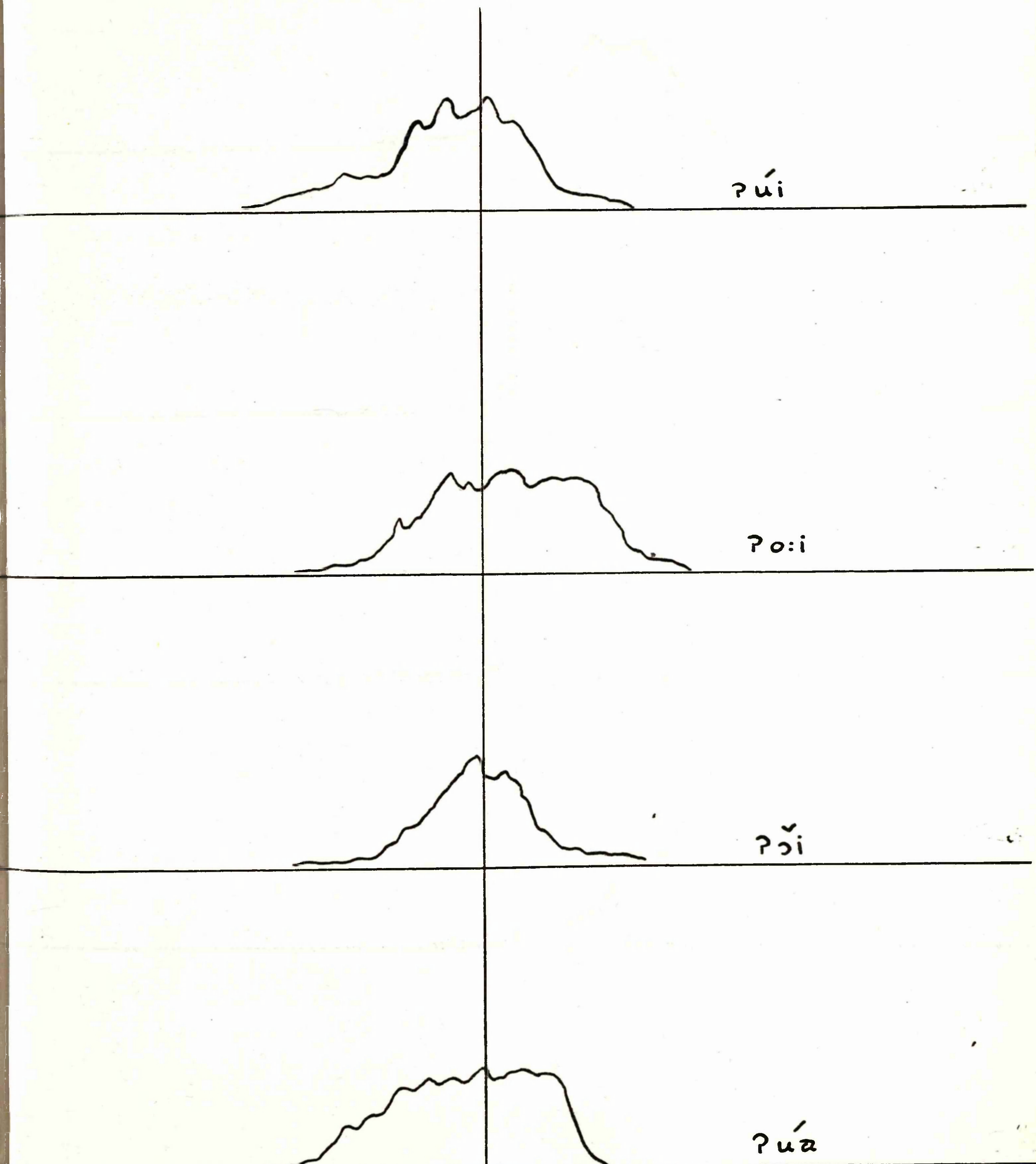
Intensity dimension

In this dimension the study was concentrated on the averaged integrated curves of the diphthongs. (see AIC IV-VII)

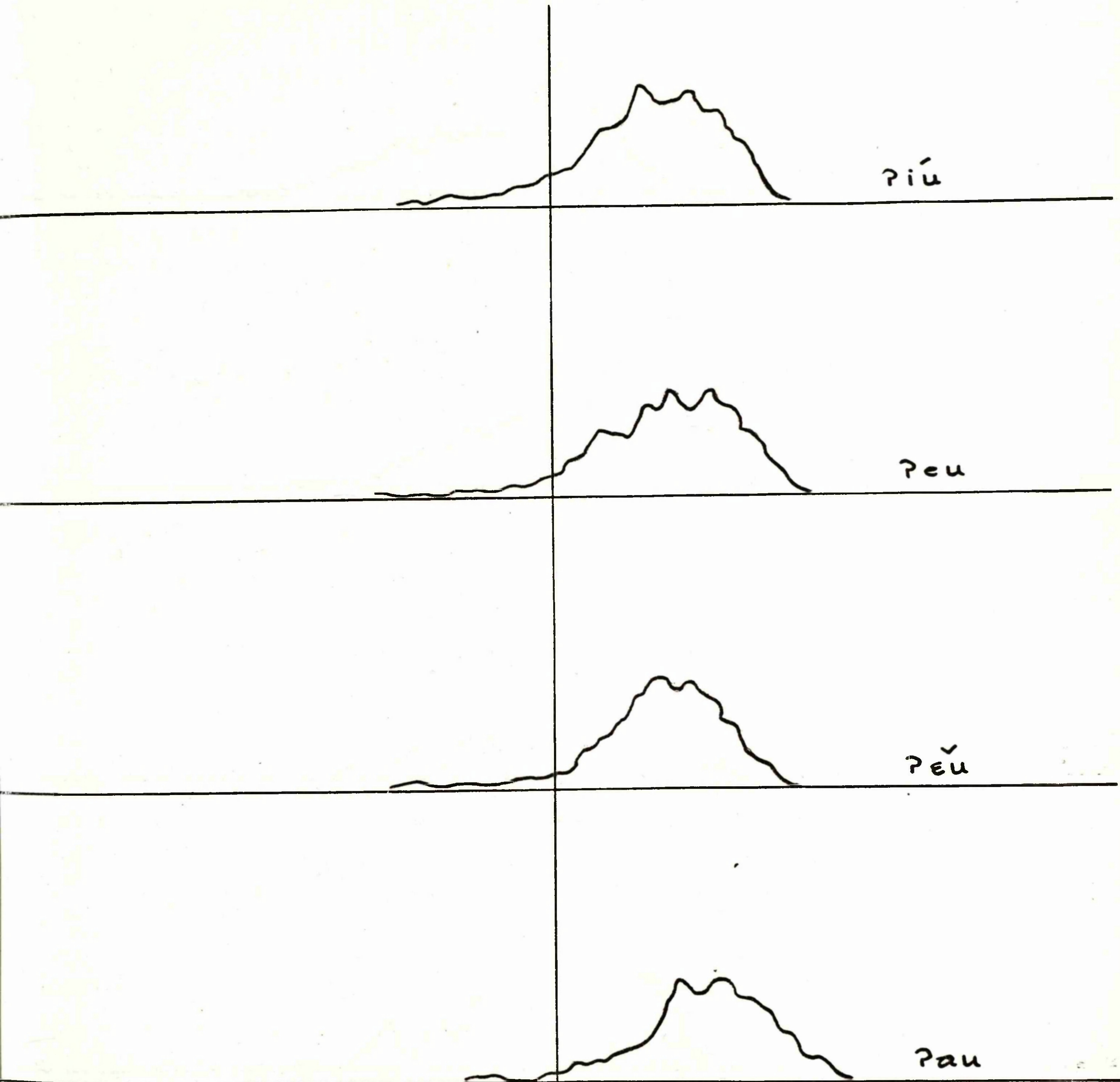
Comments on AIC IV-VII.

An interesting point is that the temporal muscular tension of those initial rounding or final rounding gesture look hardly different except in the syllables which have longer duration, [o:ɪ] and [ɛ:u]. From this point, one can apply in teaching or learning pronunciation of Thai diphthongs that the intensity of lip roundings in[ui], [o:i], [ɔi], [iu], [eu] and [ɛu] are relatively the same. In addition, for the closing diphthongs ending with lip rounding gesture, the muscular tension seems to be affected by the length of the preceding element. That is, the intensity decreases if a longer unrounding is preceding (see [kɛ̂:u]on AIC VII).

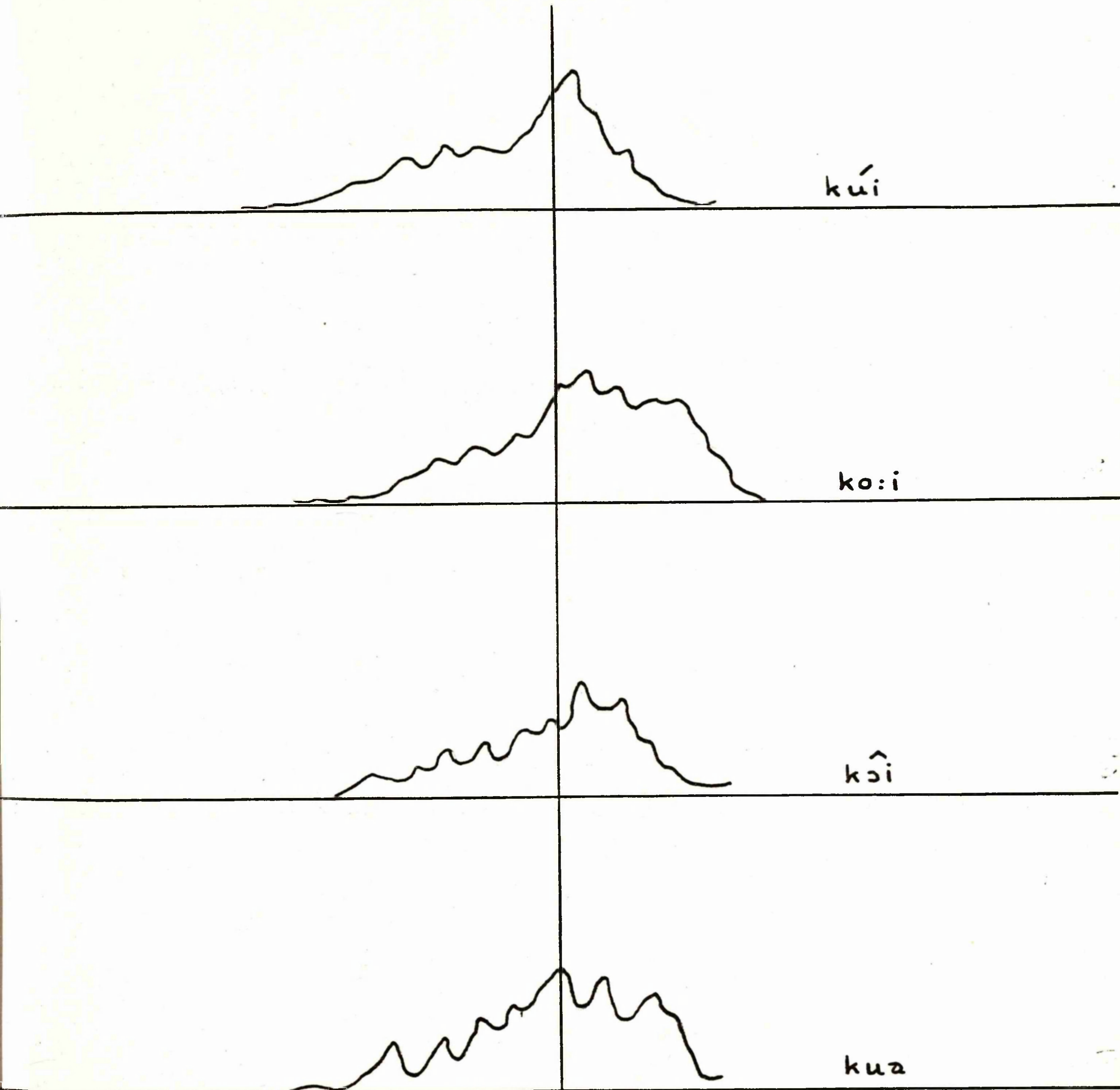
AIC IV



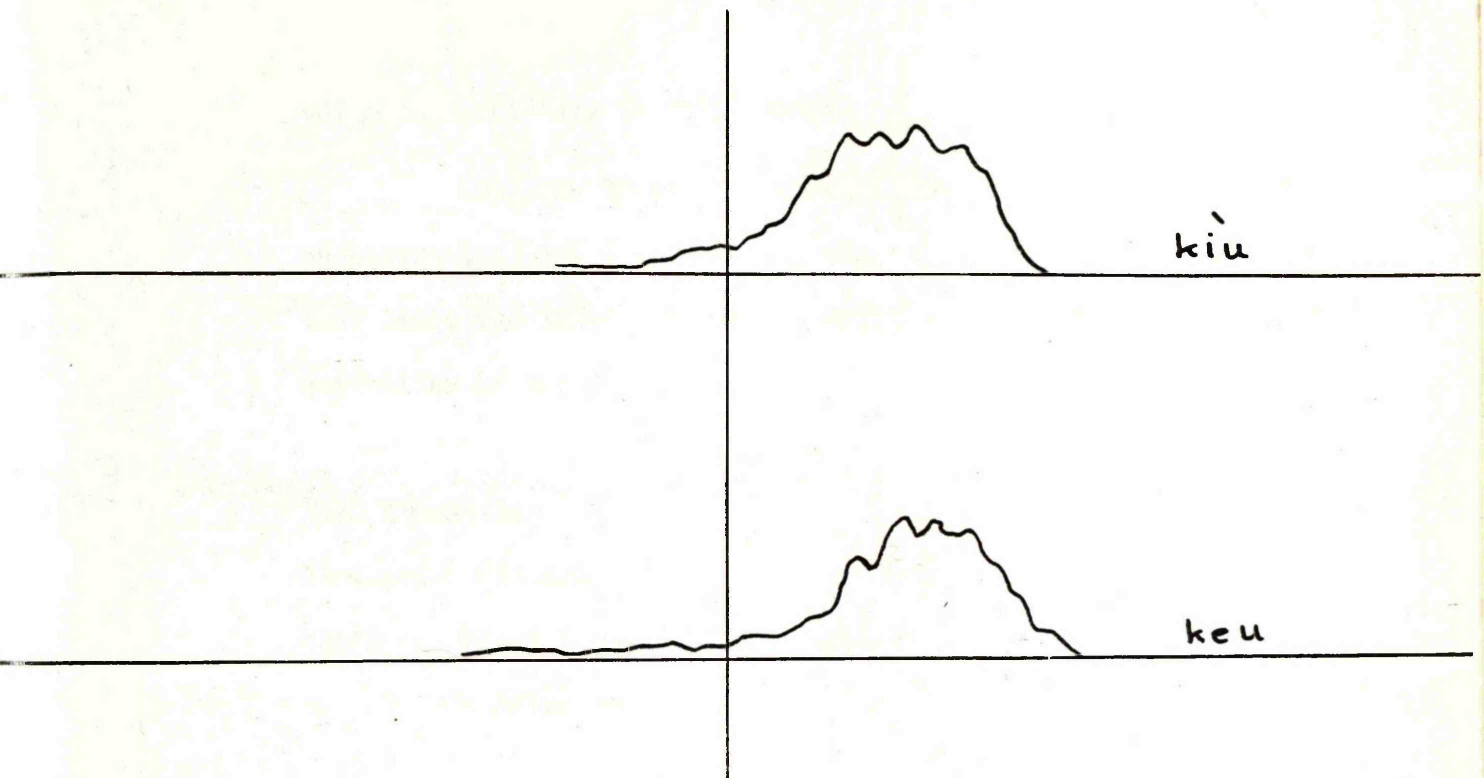
AIC V



AIC VI



AIC VII



OOI muscle activity in triphthongs.

Thai has three triphthongs, which can be transcribed phonetically: [ɯai] , [uai] , and [iau]. There was evidence that among the three triphthongs only [uai], and [iau] involved activation of the OOI muscle.

Time dimension.

Time onset (in msec.)

Table 7a Initial rounding anticipation in triphthongs (five utterances)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	260		1	280
	2	325		2	270
	3	280		3	245
?uai	4	218	kuâi	4	200
	5	182		5	303
	average	253		average	260
	SD	49.45		SD	35.14

Table 7b Final rounding time-lag in triphthongs (five utterances)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	-215		1	-220
	2	-195		2	-200
	3	-300		3	-222
?iâu	4	-210	kiâu	4	-180
	5	-240		5	-160
	average	-232		average	-196
	SD	36.96		SD	23.75

PT = Phonetic Transcription. Ao = Audio onset.
- mark indicates the EMG onset of the OOI muscle begins after the Ausio onset.

Comments on Tables 7a and 7b.

The rounding anticipatory movements for the triphthong [iau] are delayed as in the diphthongs [eu] ,[ɛu] and [au]. As might be explained, the delaying phase is even longer than in the diphthongs. For the triphthong [uai] the anticipation of rounding activity is as early as in the monophthong [u].

Time dimension of the OOI muscle activity for triphthongs.

Duration (in msec.)

Table 8 OOI muscle activity duration for initial and final rounding in triphthongs (five utterances).

PT	utterance order	EMG duration	PT	utterance order	EMG duration
	1	410		1	455
	2	505		2	400
	3	475		3	455
ʔuai	4	365	kûai	4	380
	5	330		5	490
	average	417		average	436
	SD	65.47		SD	40.17
	1	210		1	162
	2	195		2	180
	3	210		3	250
ʔîau	4	200	kîau	4	235
	5	150		5	233
	average	193		average	212
	SD	22.27		SD	34.46

Comments on Table 8.

The figures show that the initial rounding gesture in Thai triphthongs is more emphasized than the final rounding gesture. This characteristic is to be aware of in teaching triphthong pronunciation of Thai.

Intensity dimension.

By comparing between the rounding in the initial position and in the final position of the triphthongal structures, it is obvious that the initial rounding configuration has greater tension than rounding in the other position (see AIC VIII).

Comparative study of averaged integrated curves (AIC).

AIC IX-XIV show the comparison between the temporal differences of intensity dimension among monophthongs:diphthongs; monophthongs:triphthongs; and diphthongs:triphthongs.

Comments on AIC IX-XIV.

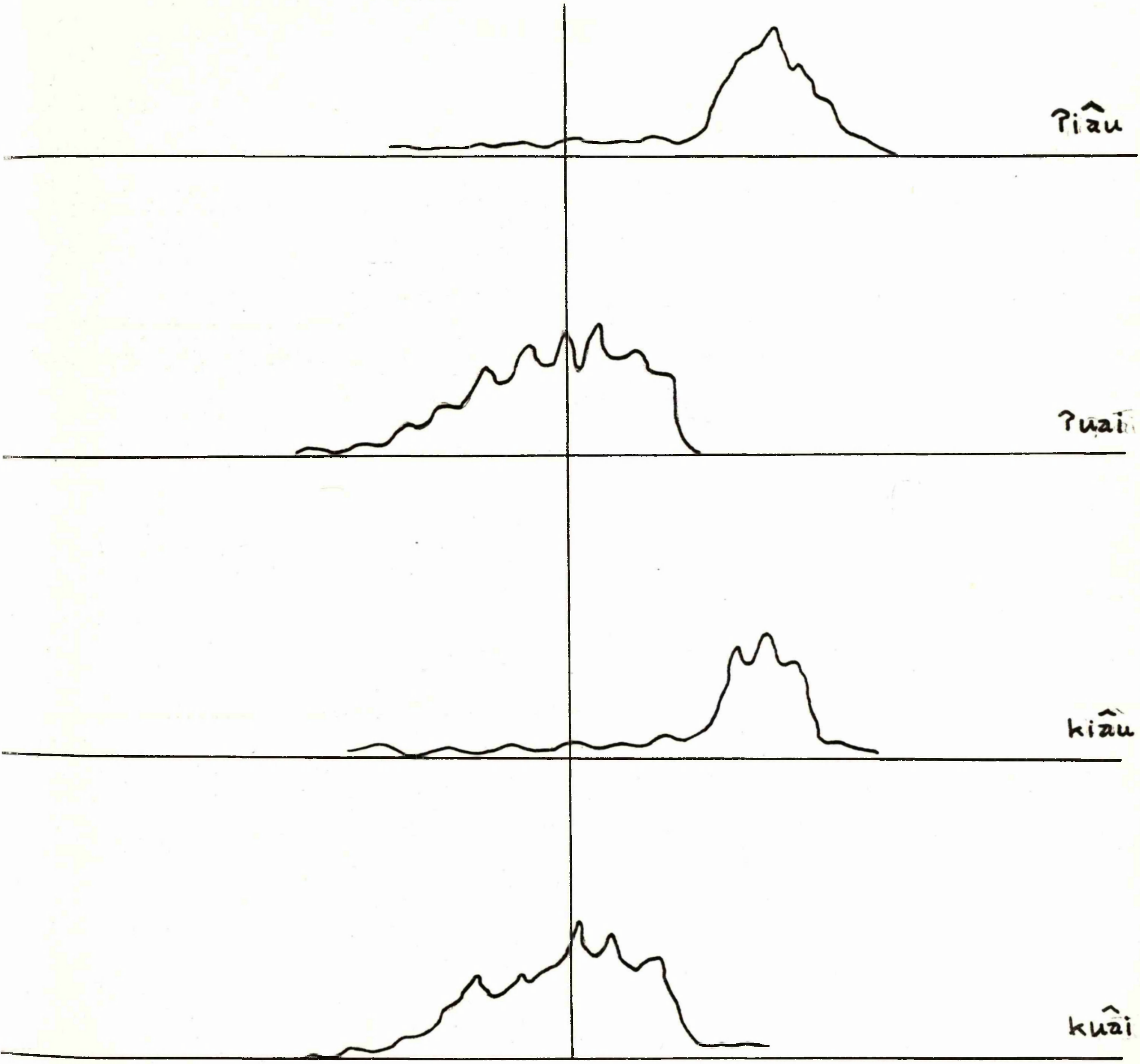
Generally, there seems to be two degrees of OOI muscular tension for rounding:

Firstly, the activity for the monophthong [u] in which the greater tension occurred: (see AIC IX, X, XII and XIII).

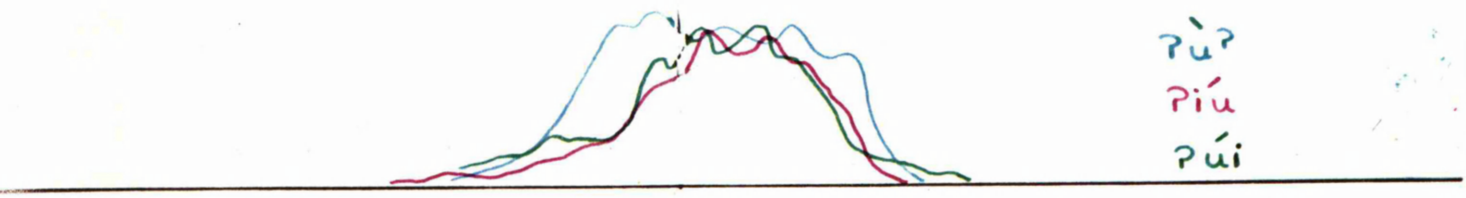
Secondly, the activity for initial and final rounding [u, o ɔ] in diphthongal and triphthongal components (see AIC XIV).

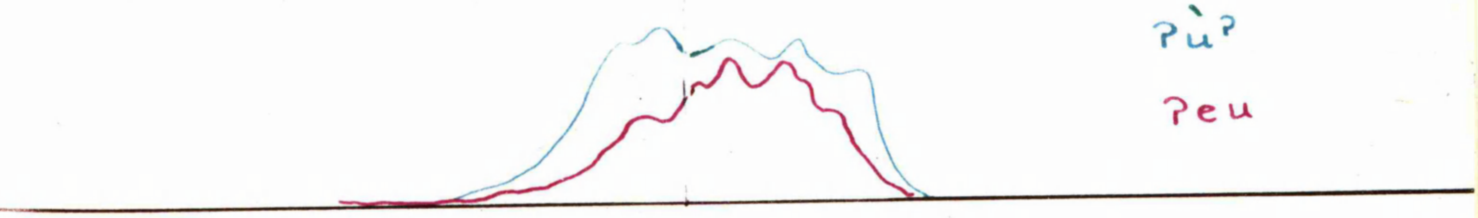
Additionally, one interesting point is that the muscular tensions for the [o:], [o:i] and the [ɔ], [ɔi] in the monophthongal and diphthongal syllables, which despite the phonemic difference, do not significantly vary. (see second and third curves on AIC X, and second and third curves on AIC XII).

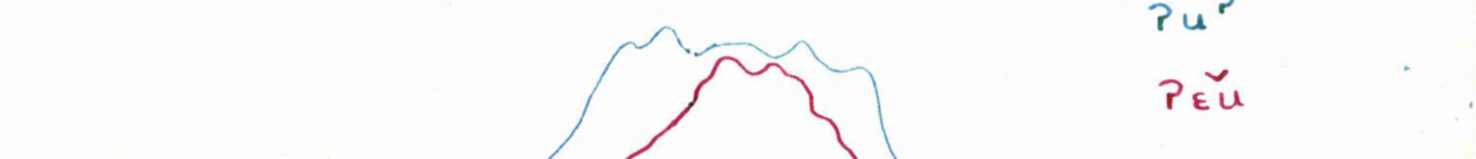
AIC VIII

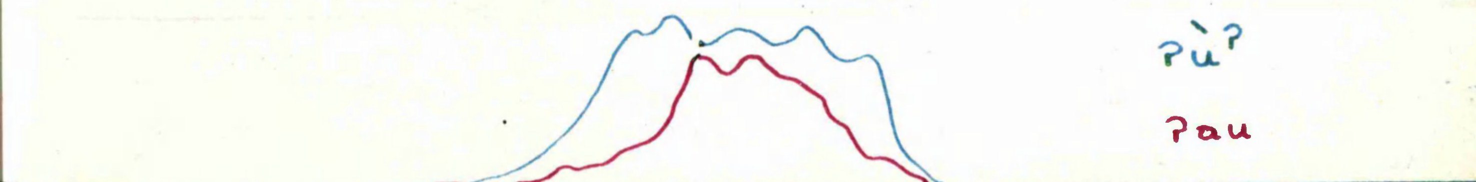


AIC IX



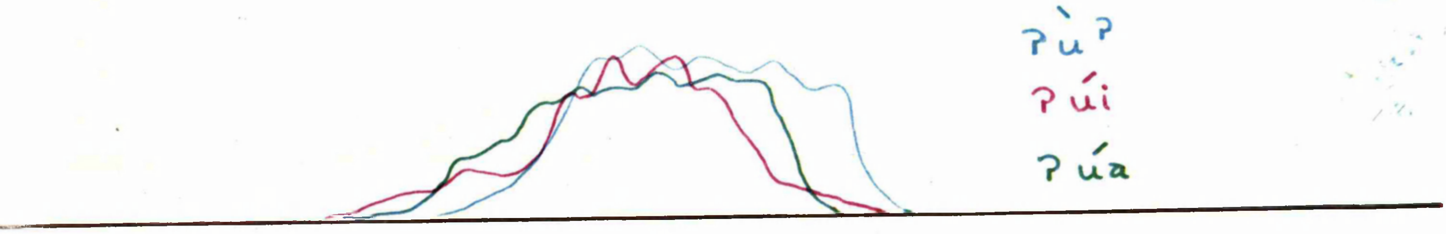


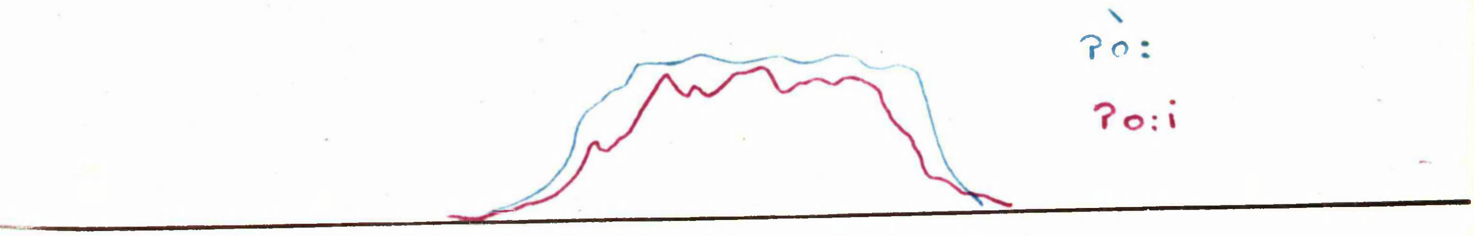




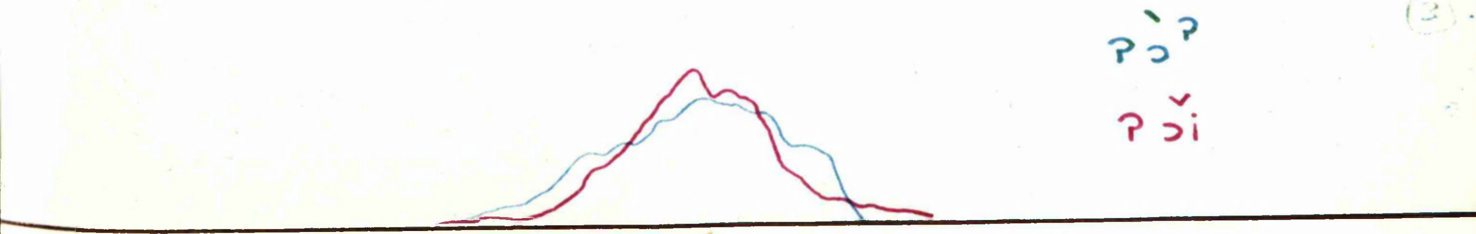
AIC X

(1)

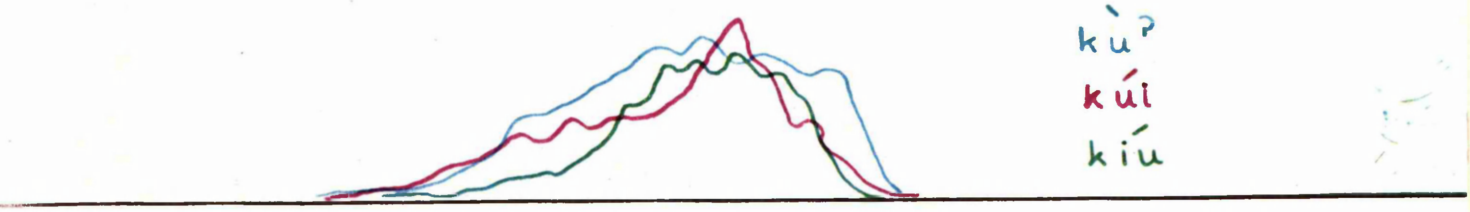


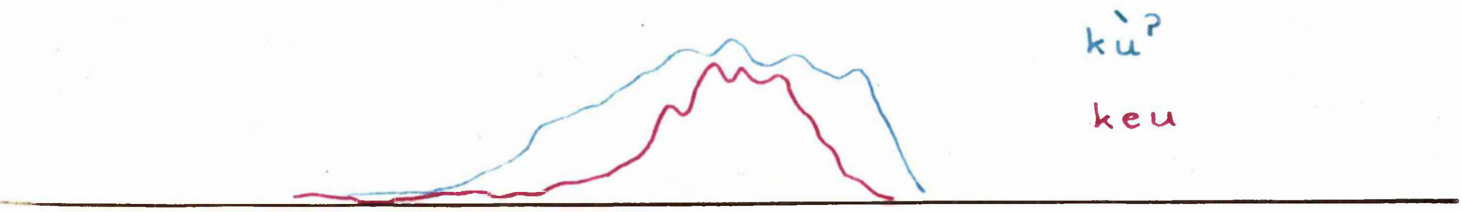


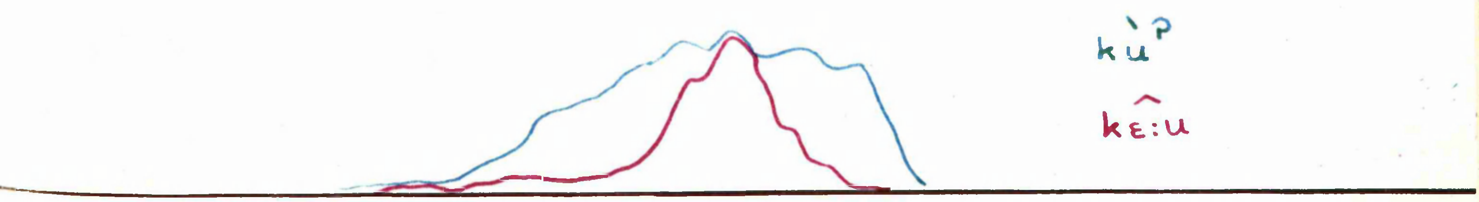
(3)

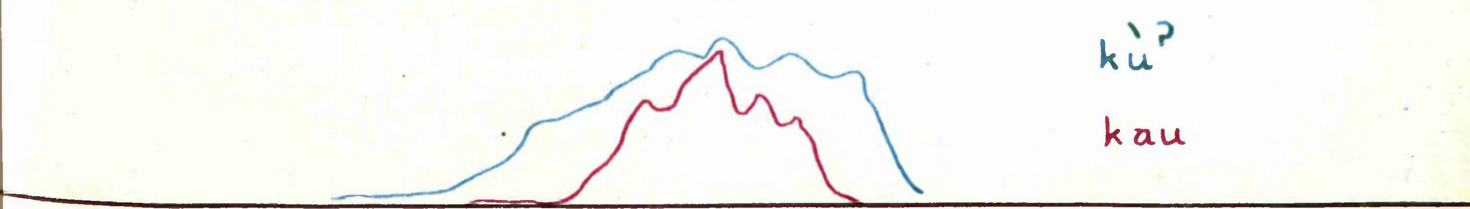


AIC XI

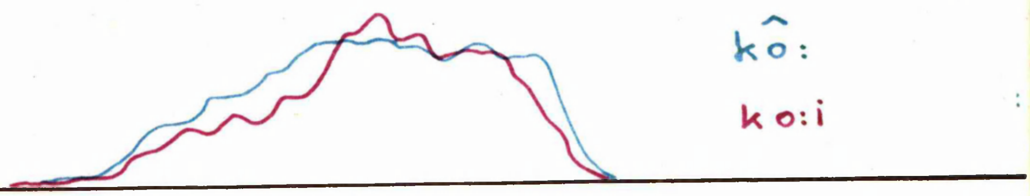


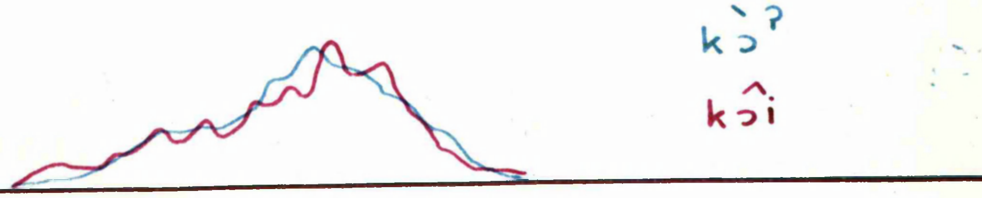




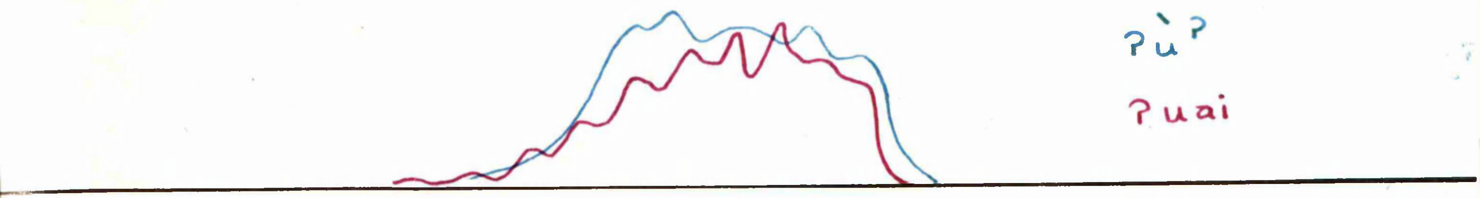


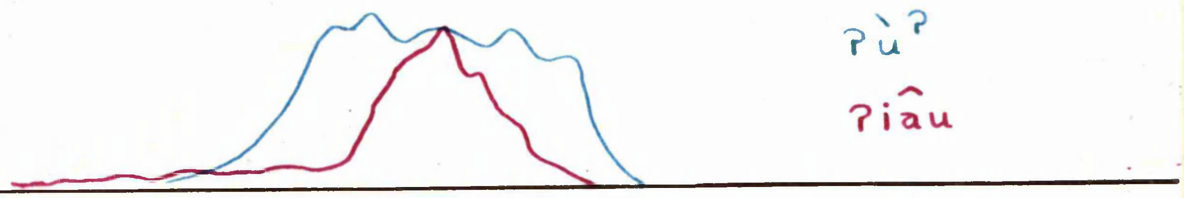
AIC XII

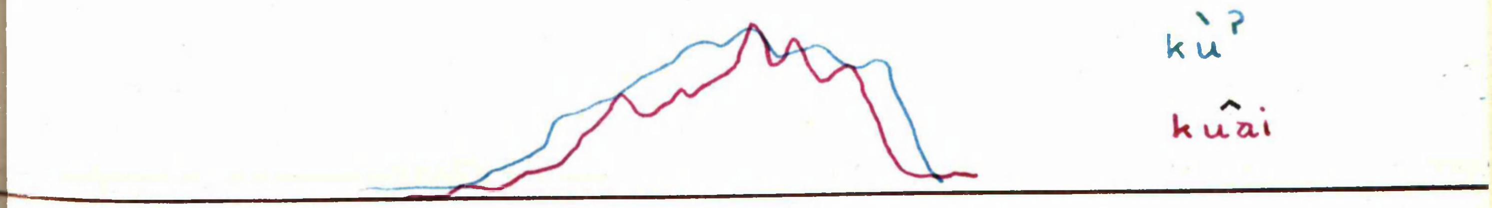


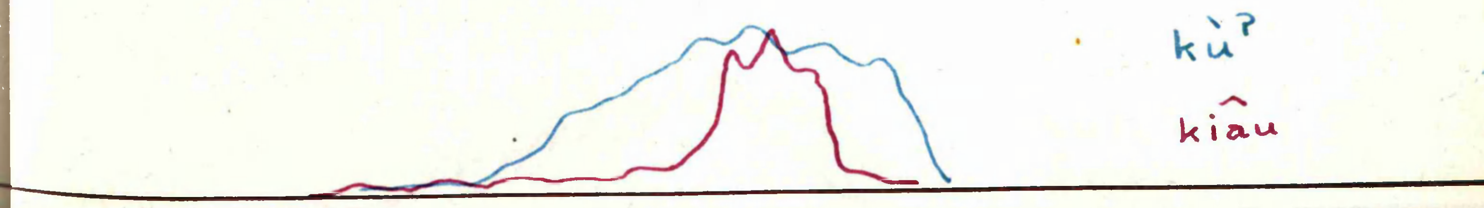


AIC XIII









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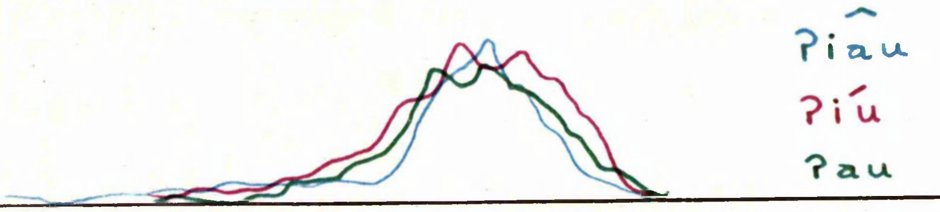
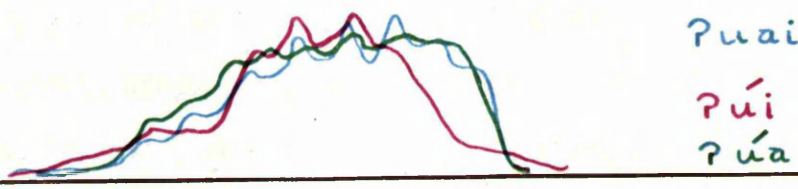
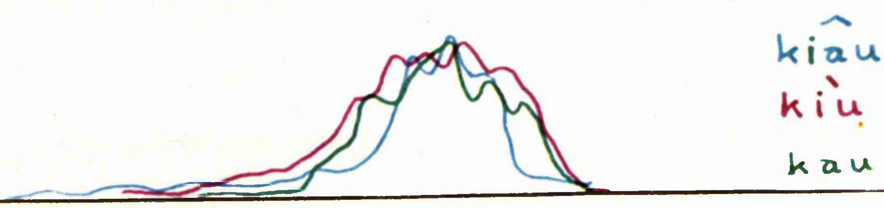
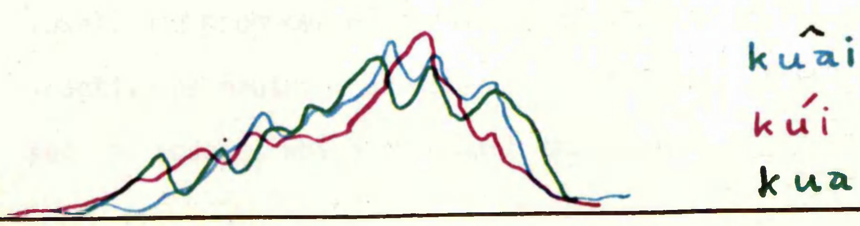
AIC XIV









CHAPTER 6

THE STYDY OF DEPRESSOR LABII INFERIORIS MUSCLE ACTIVITY

Introductory discussion of "spreading" and "unrounding".

In electromyographic research on muscular function in speech, the DLI muscle is known to play an important role in lip spreading gesture (Öhman et al., 1967: 6). According to the traditional literature of phonetics, articulatory postures of the lips were associated with two or three terms: rounded, unrounded or spread. Apparently, the terms "unrounded" and "spread." were often used interchangably in speech description. For instance in Sweet's A PRIMER OF PHONETICS (3rd, p. 18), he mentioned that "The influence of the lips may also be observed in the unrounded vowels. In the formation of the high-front vowel in *it*, the sound is made clearer by spreading out the corners of the lips".

In Pike's Lip Modifications of Vocoids (1971: 14) only one spreading gesture is demonstrated which is for the high-front vowel.

Heffner (1952: 98) employs the term unrounded in the sense of either neutral or spread, as he said, "On the basis of the behavior of the lips during their production vowels may be classified as rounded or unrounded. Unrounded vowels are produced either with the muscles of the lips quite inactive or neutral, or with the contraction of the several sets of muscles which draw back the corners of the lips and

and bare the teeth. This is called the spread lip position". As a matter of fact, the application of the terms "spread" and "unrounded" should be employed with more precision, since although a spread vowel can certainly be called an unrounded vowel, the converse is not necessarily true. An unrounded vowel is not always a spread vowel; in short, the two terms are not synonymous.

The distinctive features proposed in The Sound Pattern of English are relatively inadequate to cover the labial gesturing distinction needed to differentiate between "spreading" and "unrounding".

Traditionally, the spreading gesture of the front vowels is described both in relation to the tongue position of the vowels, and to the contraction of the mouth corners. However, the gesture for a spread vowel and for a smiling gesture are in fact normally not made in the same manner or with the same muscular movement. Observation shows that smiling does indeed need mouth corner contraction; whereas a spread vowel needs the lowering of the lip corners, which involves the activity of the DLI. Moreover, Leanderson and Lindblom (1972: 365) found the lip spreading gesture of DLI activity for i .

The following presentation is the data of EMG anticipation occurred in the productions of front vowels.

DLI muscle activity for front monophthongs.

Time dimension.

Time onset (in msec.)

Table 9 DLI anticipation for front monophthongs

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	206		1	235
	2	170		2	188
	3	240		3	178
?i:	4	165	kì:	4	160
	5	270		5	250
	average	210		average	202
	SD	40.35		SD	34.43
	1	243		1	285
	2	240		2	280
	3	188		3	210
?ì?	4	155	kì?	4	150
	5	252		5	180
	average	216		average	221
	SD	37.70		SD	53.70
	1	200		1	170
	2	210		2	240
	3	160		3	200
?é:	4	190	ké:	4	217
	5	150		5	190
	average	182		average	203
	SD	23.15		SD	23.80
	1	250		1	220
	2	205		2	202
	3	105		3	274
?é?	4	195	ké?	4	190
	5	185		5	195
	average	140		average	216
	SD	47.07		SD	30.64

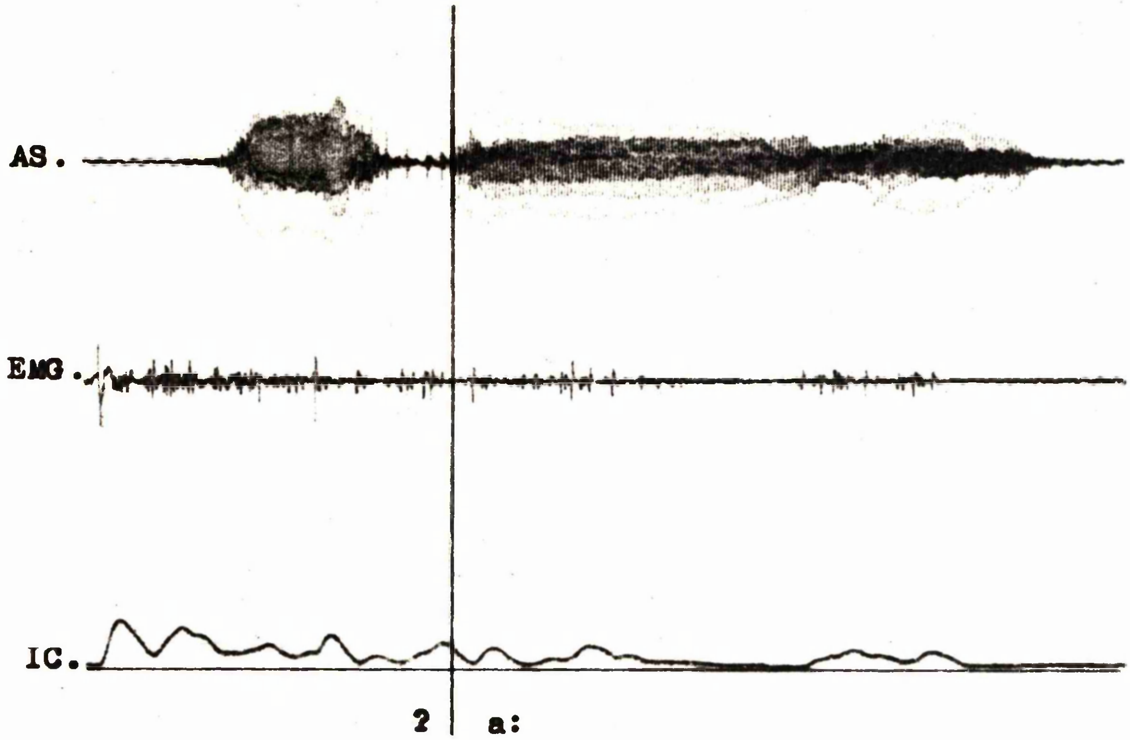
Table 9 (cont.)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	160		1	250
	2	160		2	220
	3	150		3	210
ʔɛ̂:	4	77	kɛ̀:	4	220
	5	152		5	198
	average	140		average	219
	SD	31.66		SD	17.22
	1	149		1	230
	2	240		2	217
	3	145		3	215
ʔɛ́ʔ	4	210	kɛ́ʔ	4	213
	5	177		5	208
	average	184		average	217
	SD	36.35		SD	7.33

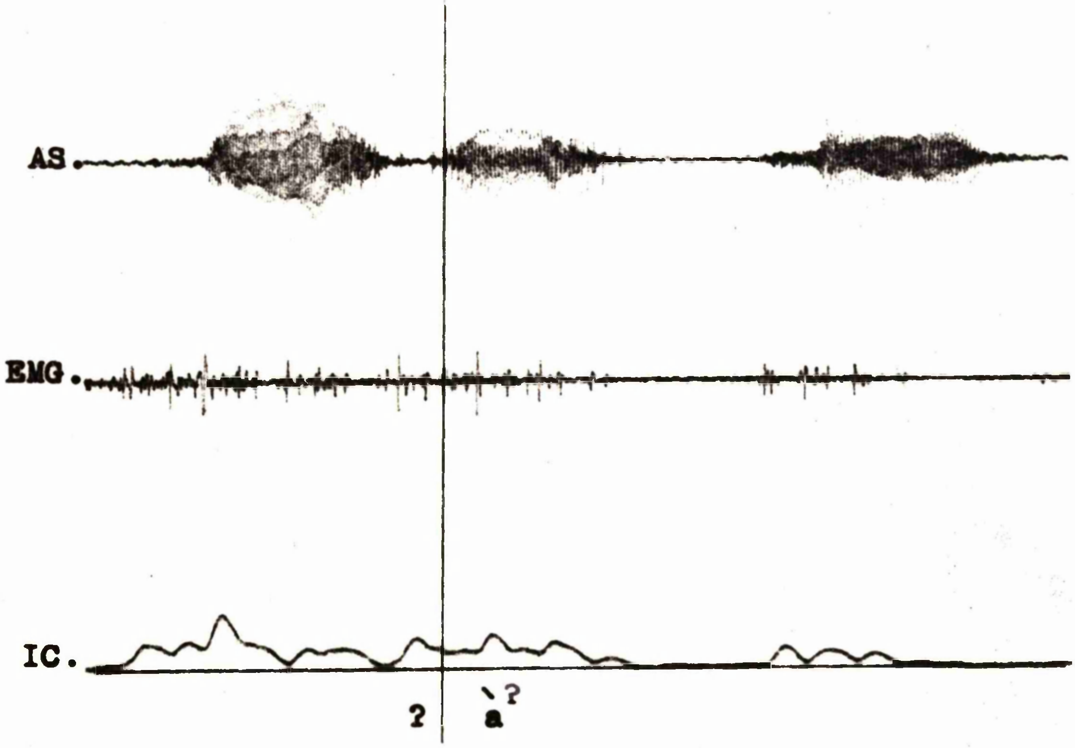
Comments on Table 9

In the syllables preceded by [?] the EMG time onset of the short vowels seem to begin consistently earlier than those of the long vowels. In the syllables preceded by [k], however, there is evidence from [kɛ̀:] and [kɛ̀ʔ] that the electromyographic onsets of the short vowels do not occur earlier than the long counterparts. Comparing among the front vowels, the muscular anticipation for the high-front vowels appears to be the longest. Nevertheless, the evidence is inconducive as to whether the anticipatory movements of [e] or [ɛ] are longer. However, the SD figures indicate rather less variation among the the anticipation figures than among those of [e] figures. Thus, it might be decided from this point that the anticipation of [ɛ] is longer than that of [e]. For [a: , a] the EMG trace is insignificant; however, in comparing with the utterances of the back unrounded, [ɯ] and [ɤ] the EMG action potentials of [a: , a] look a little more active, (see EMG XX-XXV).

EMG XX

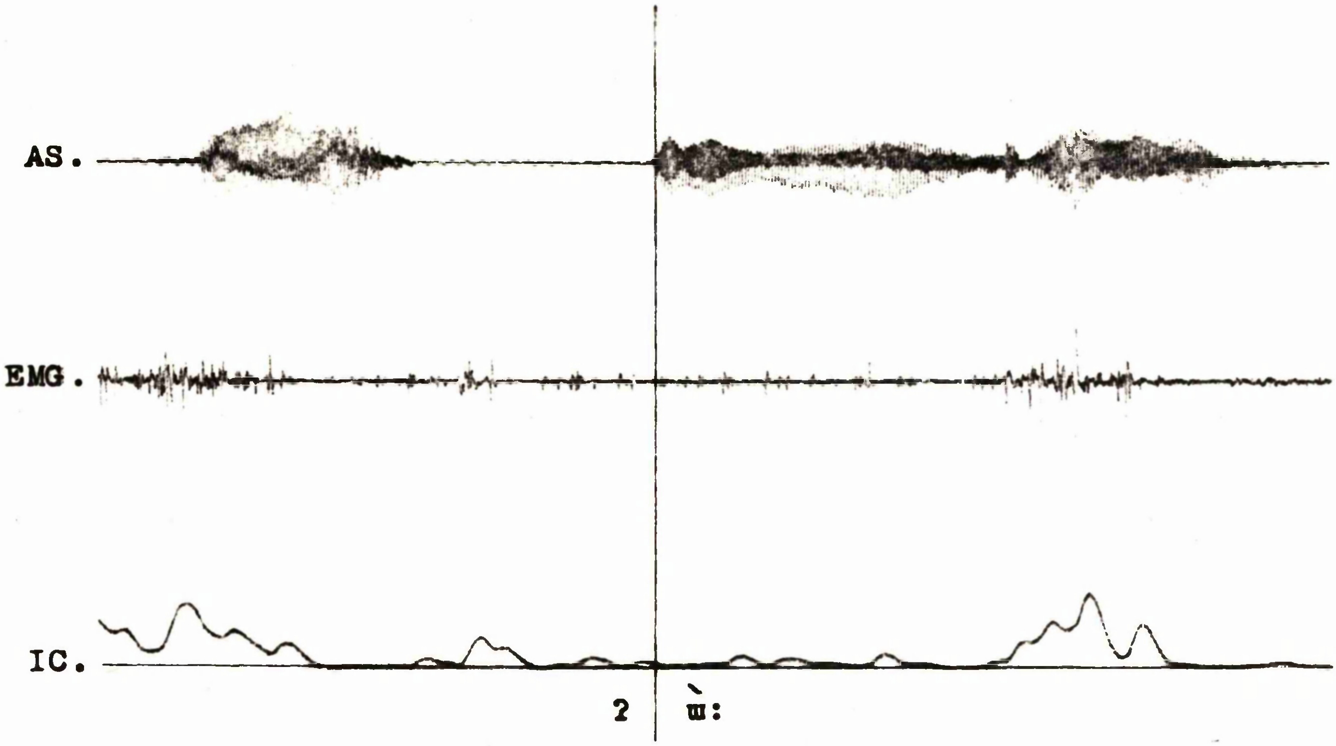


(a)

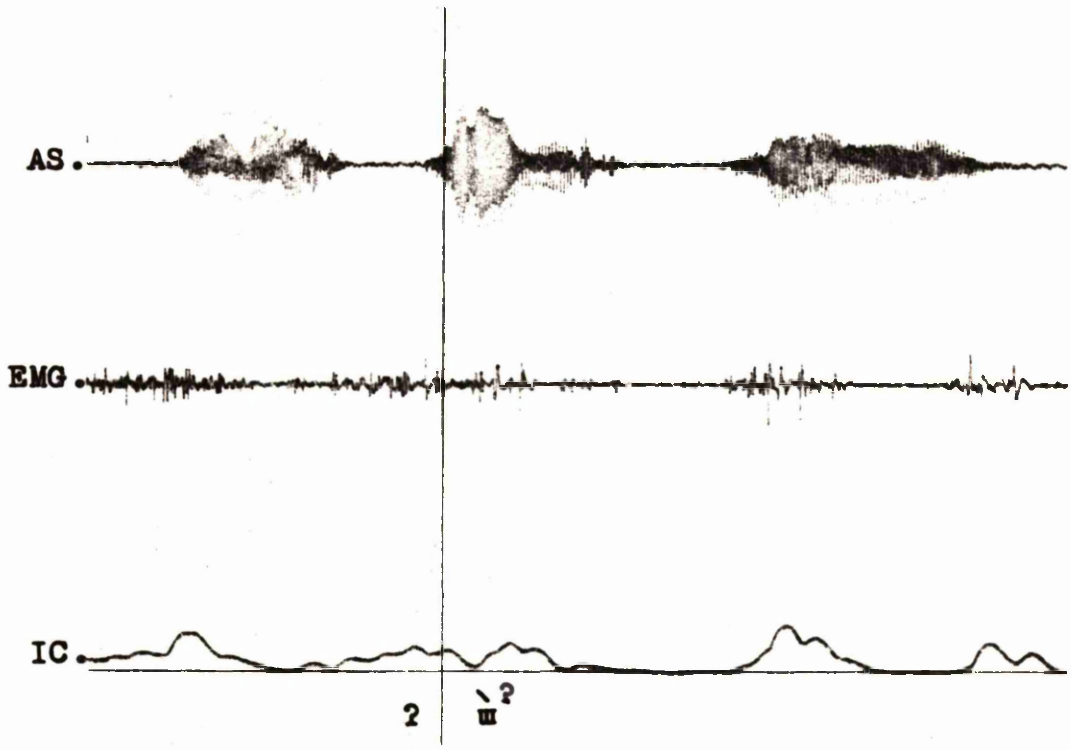


(b)

EMG XXI

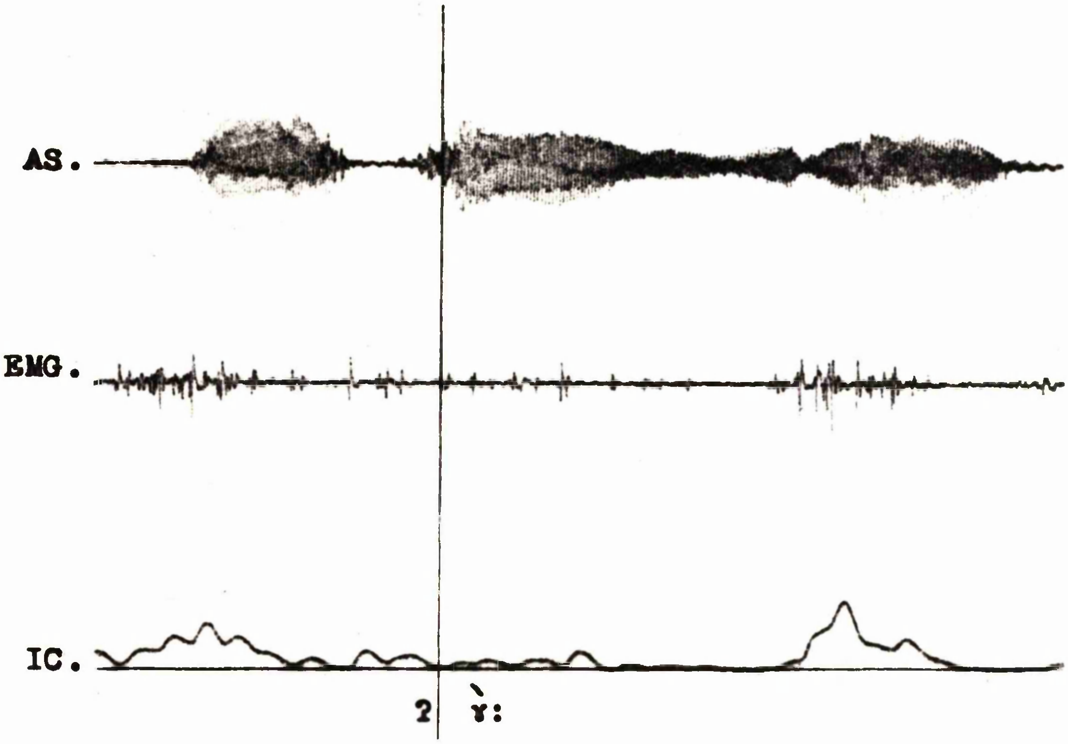


(a)

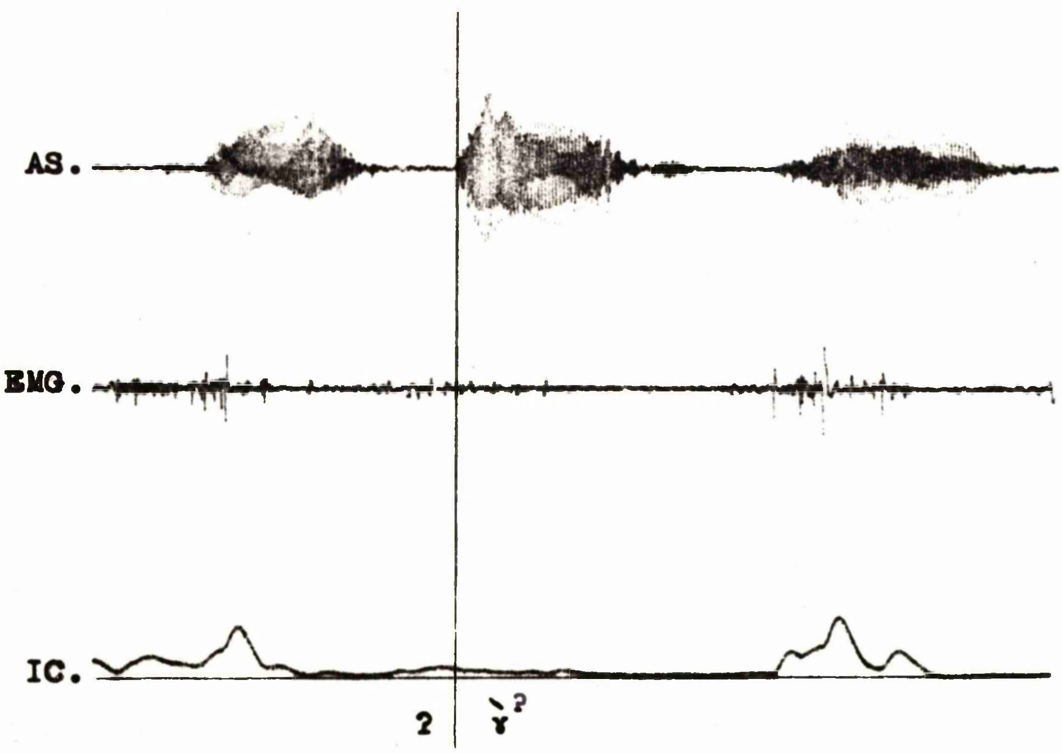


(b)

EMG XXII

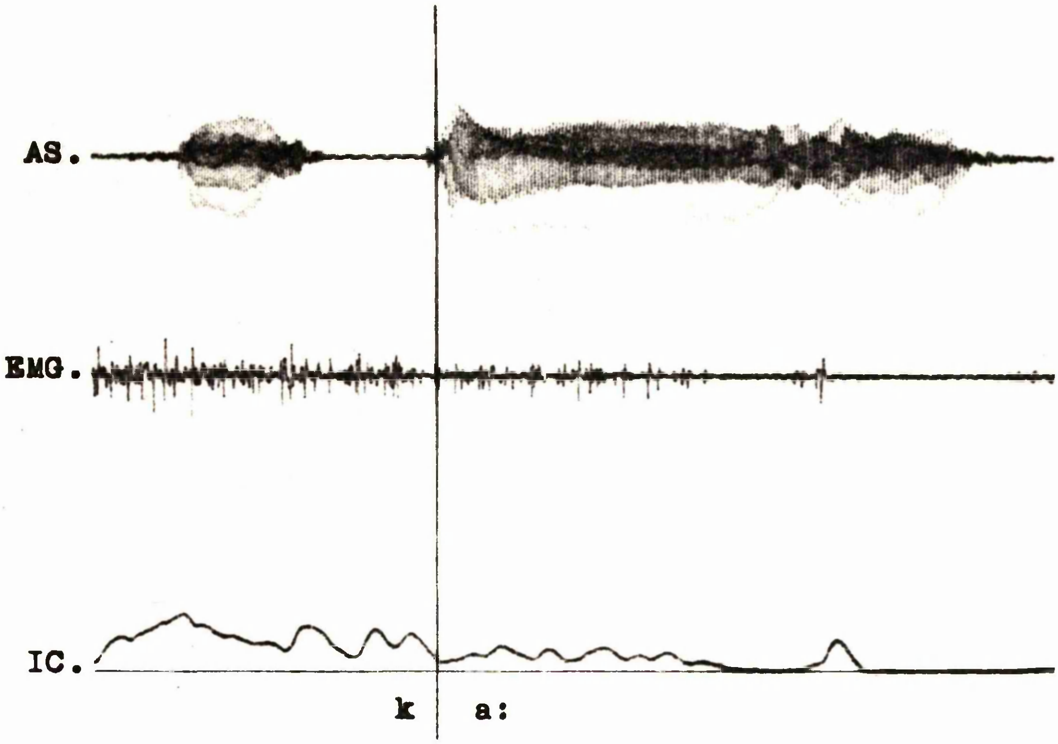


(a)

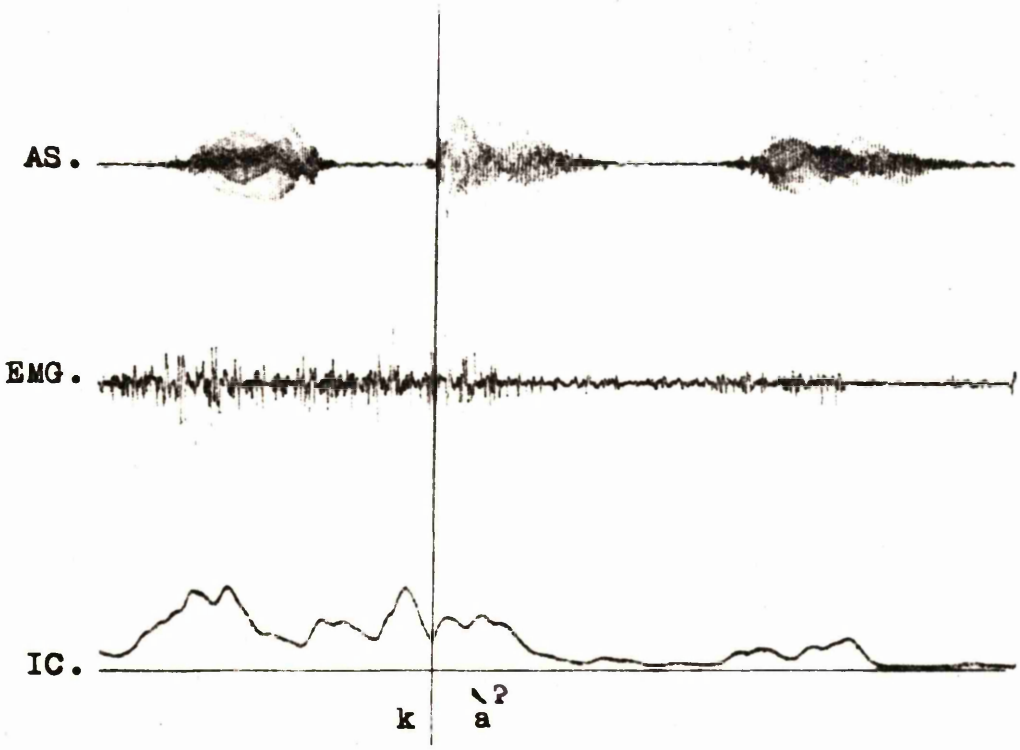


(b)

EMG XXIII

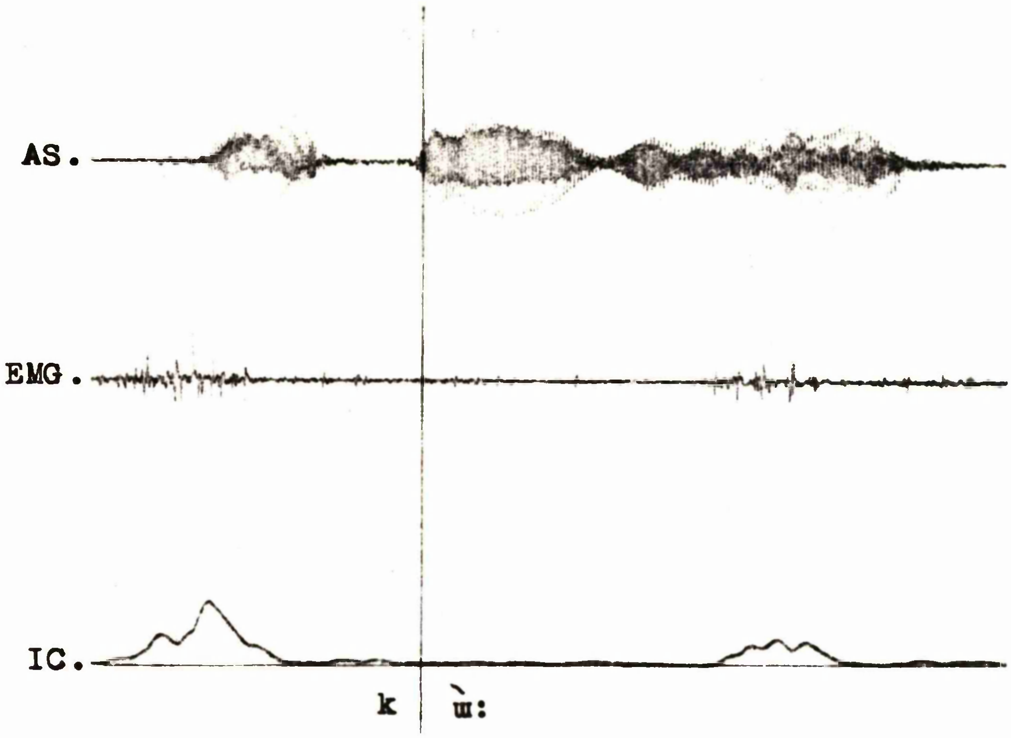


(a)

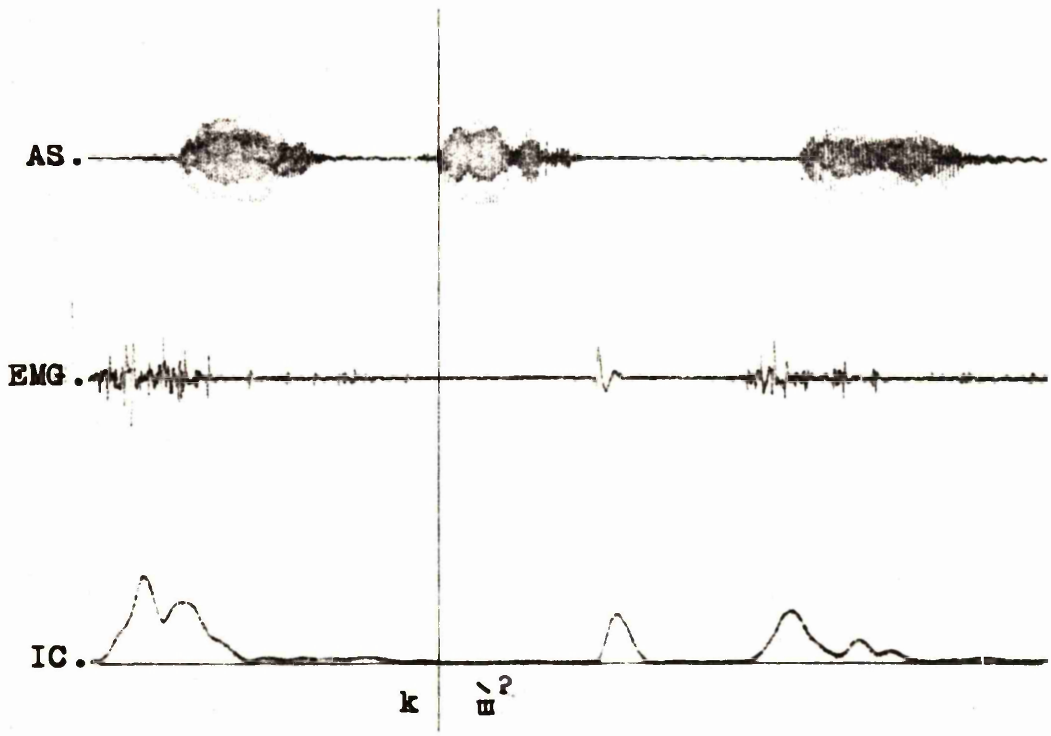


(b)

EMG XXIV

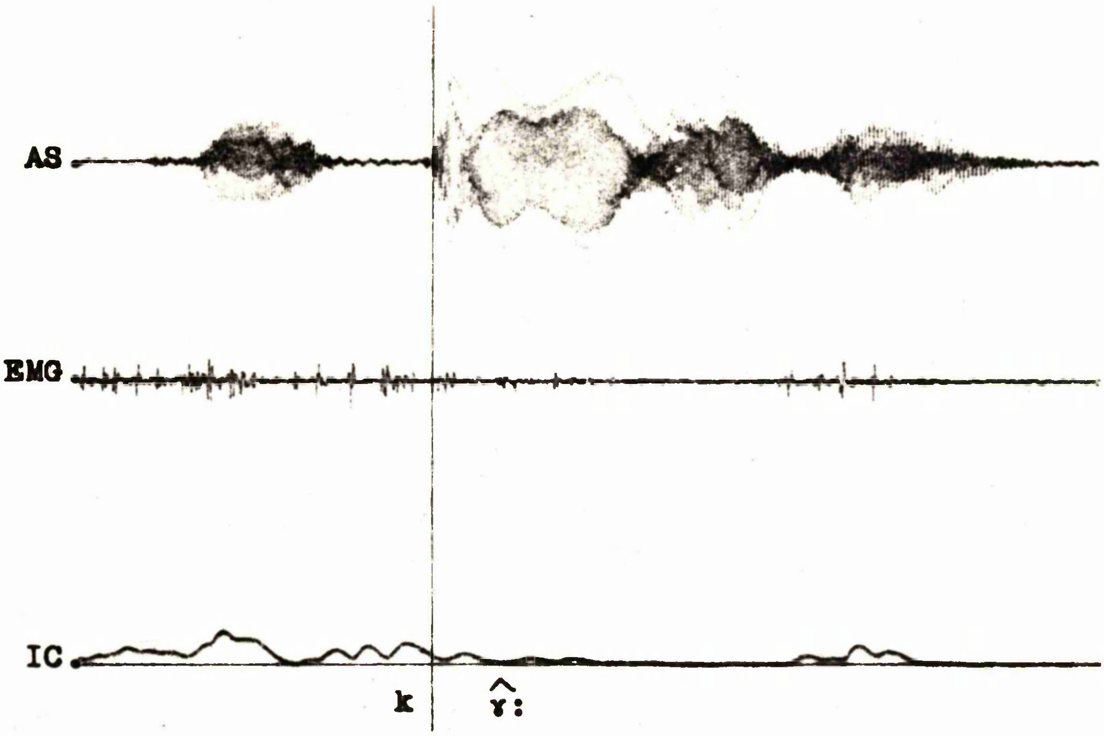


(a)

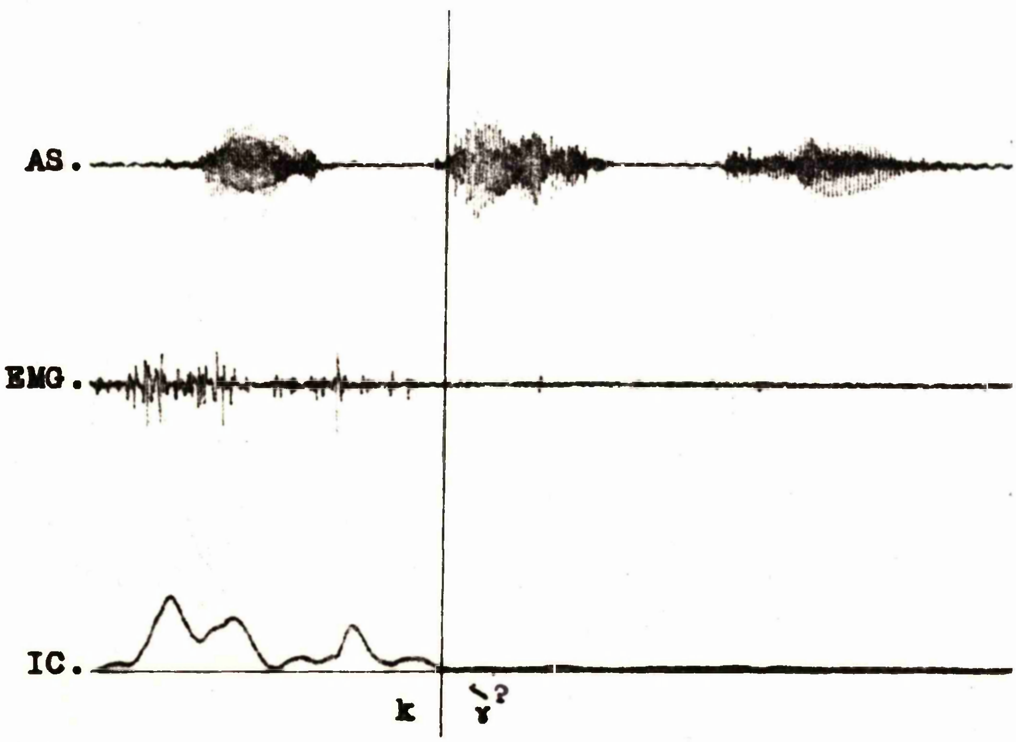


(b)

EMG $\overline{\text{XXV}}$



(a)



(b)

Time dimension of the DLI muscle activity.

Duration (in msec.)

Table 10 DLI duration of front monophthongs

(five utterances)

PT	utterance order	EMG duration	PT	utterance order	EMG duration
	1	484		1	370
	2	450		2	450
	3	553		3	330
?i:	4	450	kì:	4	310
	5	540		5	455
	average	495		average	383
	SD	43.72		SD	59.96
	1	310		1	420
	2	370		2	380
	3	335		3	300
?ì?	4	315	kì?	4	270
	5	370		5	340
	average	340		average	342
	SD	25.88		SD	53.81
	1	455		1	490
	2	540		2	500
	3	460		3	460
?é:	4	490	ké:	4	460
	5	420		5	405
	average	473		average	463
	SD	40.20		SD	33.10
	1	350		1	350
	2	315		2	300
	3	230		3	400
?é?	4	330	ké?	4	350
	5	275		5	350
	average	300		average	350
	SD	42.78		SD	31.62

Table 10 (cont.)

PT	utterancee order	EMG duration	PT	utterance order	EMG duration
	1	420		1	350
	2	430		2	430
	3	275		3	410
ʔɛ̂:	4	390	kɛ̀:	4	474
	5	385		5	375
	average	380		average	427.8
	SD	55.22		SD	66.23
	1	255		1	325
	2	375		2	330
	3.	260		3	250
ʔɛ̀ʔ	4	310	kɛ̀ʔ	4	300
	5	325		5	340
	average	305		average	309
	SD	44.38		SD	32.31

Comments on Table 10 .

There is evidence that the EMG durations of the long vowels are not twice as long as the short counterparts as has been suggested in earlier acoustical description of Thai(Abramson 1962: 107). The durational differences between the long and the short counterparts are approximately 10-24 percent for the syllables preceded by [k], and 15-31 percent for the syllables preceded by [?]. Durational differences among the same vowel phoneme following [?] and [k] also occur, but there is no regularity that one group of the syllables is consistently longer than the other.

Intensity dimension of DLI muscle activity.

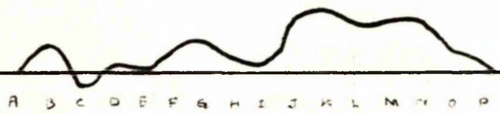
The temporal differences among the intensity activities of DLI for the front vowels are demonstrated by difference curves. (see DC III-IV).

Comments on DC III-IV.

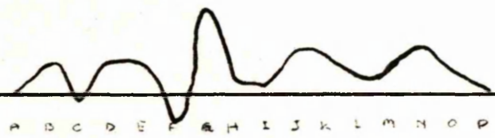
The slight differences of intensity activity between [i:] , [e:], and [i:], [ε:] do not appear to be distinctive . In spite of that, the difference curves between [i], [e] and [i], [ε] reveal that the temporal tension for the [e] is a little greater than for the [ε].

Thus, according to the temporal differences illustrated through the difference curves, two groups of vowels can be categorized: one with higher tension, [i:] , [e:], and [ε:] , the other with lower tension, [i] , [e] , and [ε] .

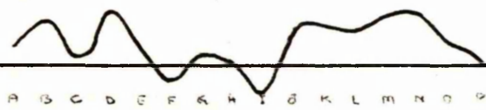
DC III



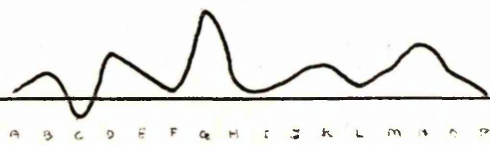
ʔi: ʔìʔ



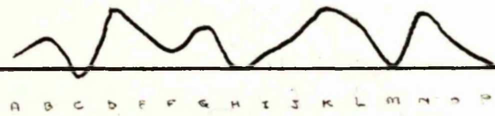
ʔi: ʔé:



ʔi: ʔéʔ

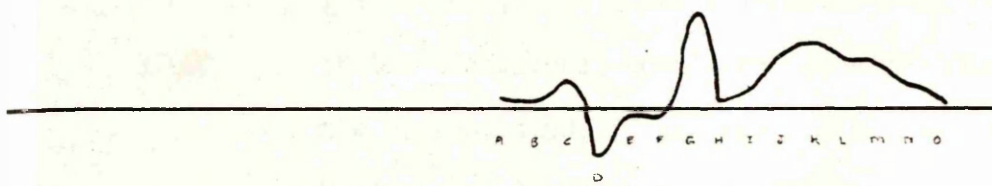


ʔi: ʔɛ̂:

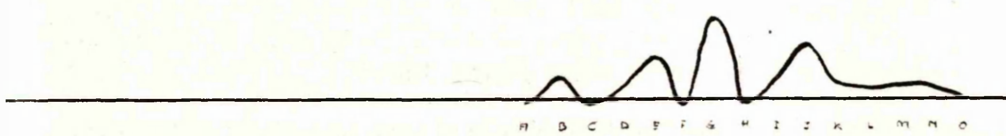


ʔi: ʔɛ̀

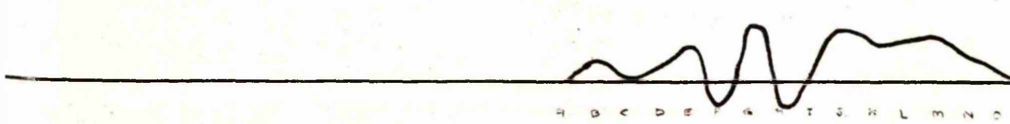
DC IV



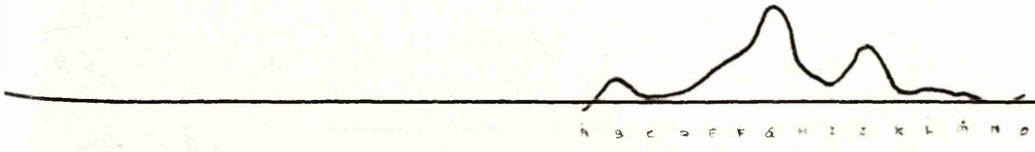
kì: kìʔ



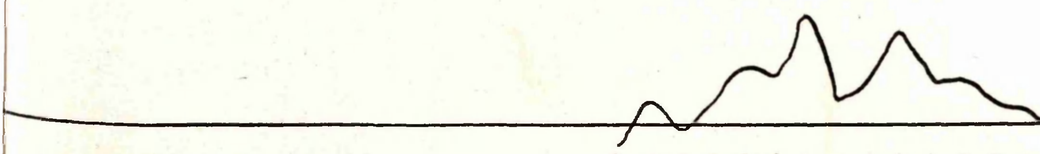
kì: ké:



kì: kéʔ



kì: kɛ̀:



kì: kɛ̀ʔ

According to the result, [i:], [e:], [ɛ:] [i], [e], [ɛ] are transposed from their usual positions in the traditional vowel arrangement. However, the result of the present study is congruent with the EMG investigation on English and American vowels (Raphael, 1971).

DLI muscle activity for diphthongs.

The Thai diphthongs, in which one component is a front vowel were investigated in order to study the activity or the DLI muscle for the front vowel component.

Time dimension.

Time onset (in msec.)

Table 11 DLI anticipation for spreading gesture in diphthongs (five utterances)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	115		1	205
	2	240		2	250
	3	260		3	225
ʔíu	4	150	kíu	4	245
	5	230		5	260
	average	199		average	237
	SD	56.25		SD	19.65

Table 11 (cont.)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	190		1	240
	2	228		2	212
	3	210		3	232
?eu	4	230	keu	4	130
	5	250		5	302
	average	222		average	223
	SD	20.25		SD	55.46
	1	105		1	166
	2	123		2	145
	3	210		3	222
?ɛ̌u	4	182	kɛ̂:u	4	248
	5	250		5	174
	average	174		average	191
	SD	53.85		SD	38.05
	1	292		1	245
	2	182		2	270
	3	215		3	188
?i:a	4	90	ki:a	4	250
	5	270		5	290
	average	210		average	248
	SD	71.46		SD	34.23
	1	130		1	93
	2	122		2	118
	3	205		3	220
?ai	4	149	kai	4	182
	5	130		5	115
	average	147		average	146
	SD	30.23		SD	47.60

Table 12 DLI time-lag for spreading gesture in diphthongs.

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	-95		1	-95
	2	-50		2	-120
	3	-85		3	-190
	4	-85		4	-170
ʔúi	5	-150	kúi	5	-110
	average	-93		average	-137
	SD	-32.34		SD	-36.55
	1	-240		1	-290
	2	-235		2	-280
	3	-280		3	-320
	4	-240		4	-250
ʔo:i	5	-256	ko:i	5	-290
	average	-250		average	-286
	SD	-16.50		SD	-22.45
	1	-40		1	-130
	2	-70		2	-140
	3	-50		3	-200
ʔɔ̌i	4	-78	kɔ̂i	4	-140
	5	-90		5	-210
	average	-66		average	-164
	SD	-18.26		SD	-33.82
	1	-205		1	-240
	2	-210		2	-280
	3	-295		3	-300
ʔɤ:i	4	-255	kɤ:i	4	-225
	5	-260		5	-230
	average	-245		average	-255
	SD	-33.61		SD	29.66

PT = Phonetic Transcription
Ao = Audio onset
- mark indicates EMG onset began after Audio onset.

Comments on Tables 11 and 12.

Normally, in the articulations of [i:a], [iu] , [eu], [εu], and [ε:u] anticipation of DLI precedes the voicing of the vowels. Where front vowels are the final elements, movements of DLI, on the other hand, were delayed until sometime after the starting of the audio signal. In the latter case, the movements also depend on whether the initial vowels are of the short or long type. If the initial elements are long, for example, [o:i]and [ɤ:i], then the DLI activity will be even more postponed than in the components initiated with a short vowel, for example, [ui] and [ɔi] . In other words, the quantity of the initial element can be correlated with the movements of the final element. Generally, activity of the DLI electromyogram which exceeds 190 msec. either before (in case of[i:a] and [ε:u]) or after (in case of[o:i] and[ɤ:i]) the onset of the acoustic signal seems to indicate that the first element is of a long quantity.

The short diphthong [ai] appears to be exception to the above in that instead of the expected DLI time-lag, as for [ui] , [o:i] , [ɔi] , [ɤ:i] etc., that delays the onset of spreading gesture in this case.

The SD figures indicate high variation in [keu] and [?i:a]. It may due to one reason that is the two words are meaningless in the present pronunciation of Thai.

Time dimension of the DLI muscle activity.

Duration (in msec.)

Table 13 DLI duration for spreading gesture in diphthongs.

(five utterances)

PT	utterance order	EMG duration	PT	utterance order	EMG duration
	1	163		1	192
	2	290		2	230
	3	270		3	210
?íu	4	190	kìu	4	290
	5	280		5	275
	average	239		average	239
	SD	51.80		SD	37.50
	1	235		1	280
	2	210		2	300
	3	240		3	300
	4	320		4	210
?eu	5	290	keu	5	350
	average	259		average	288
	SD	40.05		SD	45.34
	1	230		1	310
	2	120		2	285
	3	150		3	380
?ɛ̌u	4	210	kɛ̂:u	4	387
	5	270		5	300
	average	196		average	332
	SD	54.25		SD	45.55
	1	482		1	370
	2	400		2	342
	3	442		3	390
	4	330		4	515
?i:a	5	615	kī:a	5	585
	average	454		average	440
	SD	95.02		SD	93.44

Table 13 (cont.)

PT	utterance order	EMG duration	PT	utterance order	EMG duration
	1	120		1	240
	2	190		2	130
	3	170		3	100
?úi	4	264	kúi	4	110
	5	140		5	135
	average	177		average	143
	SD	49.80		SD	50.16
	1	75		1	95
	2	85		2	80
	3	115		3	60
	4	132		4	150
?o:i	5	80	ko:i	5	115
	average	97		average	100
	SD	22.20		SD	30.82
	1	180		1	105
	2	125		2	125
	3	160		3	130
?ɔ̌i	4	160	kɔ̂i	4	90
	5	140		5	165
	average	153		average	123
	SD	18.87		SD	25.41
	1	120		1	150
	2	115		2	90
	3	95		3	110
	4	100		4	70
?ɤ:i	5	95	kɤ:i	5	180
	average	105		average	120
	SD	10.50		SD	40
	1	115		1	112
	2	100		2	190
	3	130		3	130
?ai	4	98	kai	4	175
	5	135		5	100
	average	116		average	141
	SD	15.08		SD	35.21

Comments on Table 13 ..

The average figures show that the averaged durations of DLI action potentials are greater for the initial front vowels than for the final front vowels in diphthongs of the same functional length. In the [i:a] syllable the duration of the front element is more or less in the same range as that of the monophthong [i:]. Nevertheless, in the [eu] [ɛu] ,[ɛ:u] and [ɪu] the averaged durations of the initial front vowels are less than their monophthongal correspondences. Evidently, the shortest duration belongs to the final element of [uɪ] ,[o:ɪ] [ɤ:ɪ] ,[ɔɪ] and [aɪ]

The SD figures of those diphthongs in which spreading gesture occurs initially, [ʔɪ:a], [kɪ:a] , indicate high variation. One reason to be taken into account due to meaningless characteristic of the words.

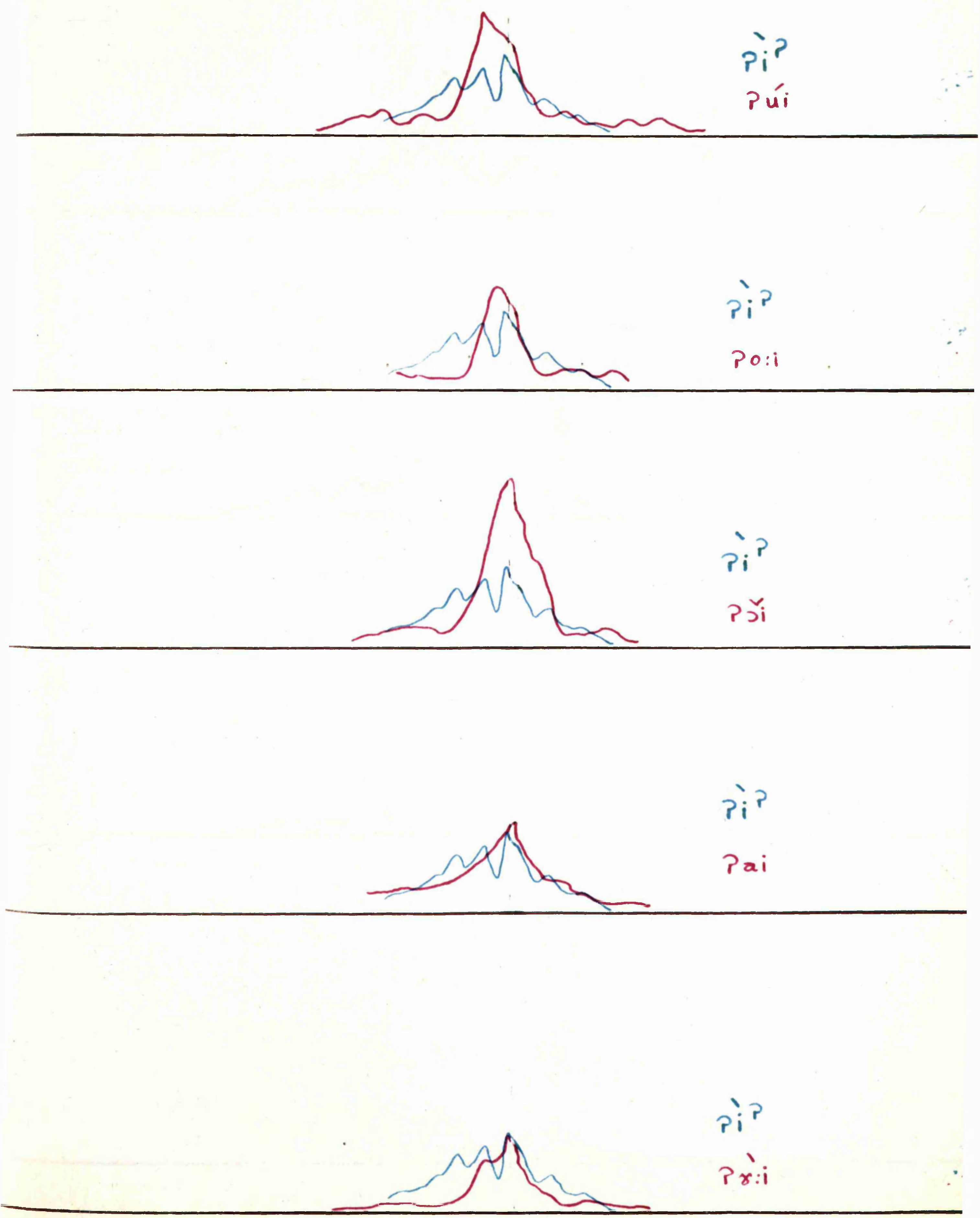
Intensity dimension of the DLI muscle activity.

The comparisons were made not only among the front vowels in diphthongs but also with the corresponding monophthongs, (see AIC XV-XIX).

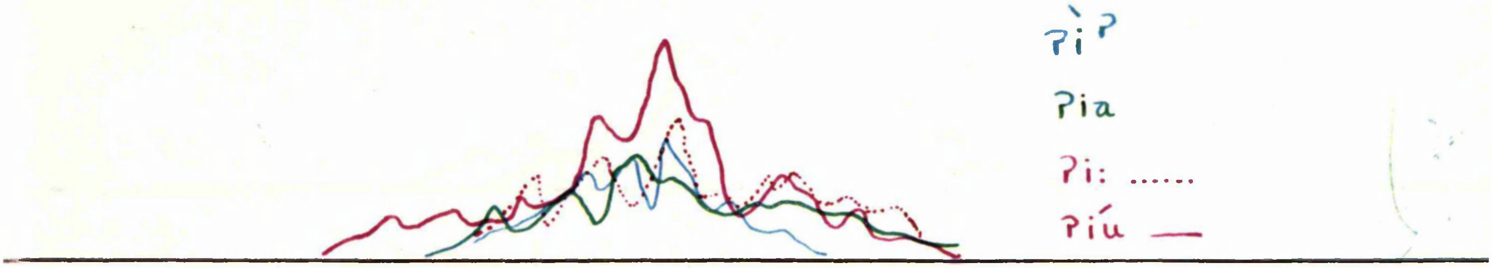
Comments on AIC XV-XIX.

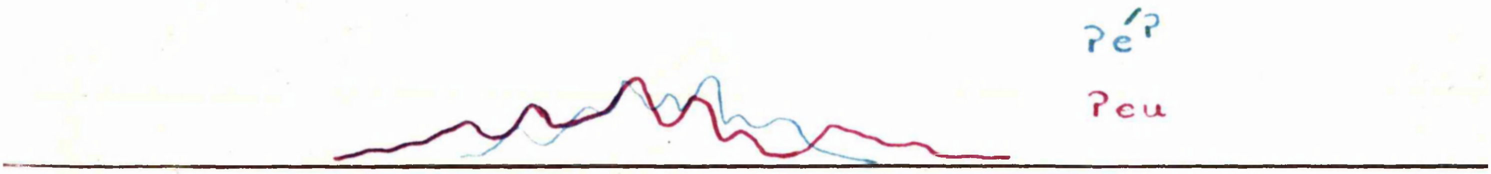
The DLI intensity activity of the initial and the final front elements of diphthongs do not demonstrate the same degree of muscular tension. The tension for the initial i seems to be the greatest while the temporal tension for the i

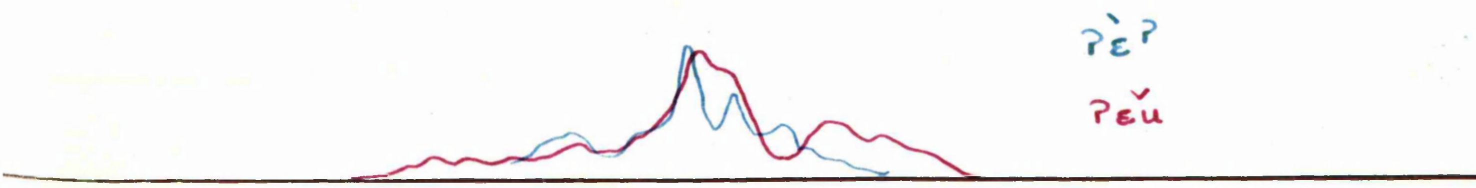
AIC $\overline{\underline{XV}}$

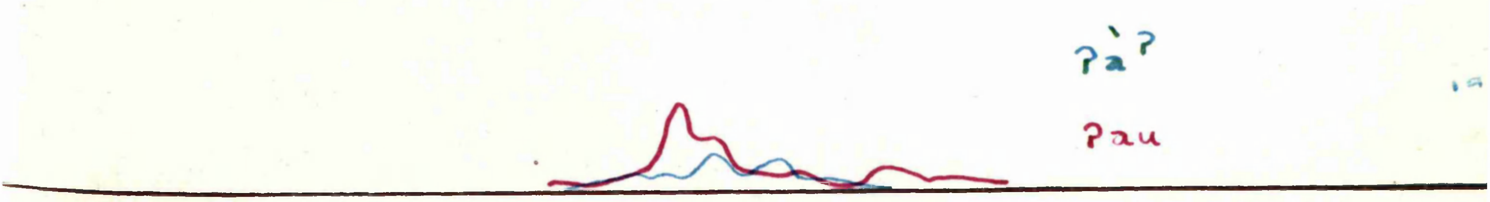


AIC XVI

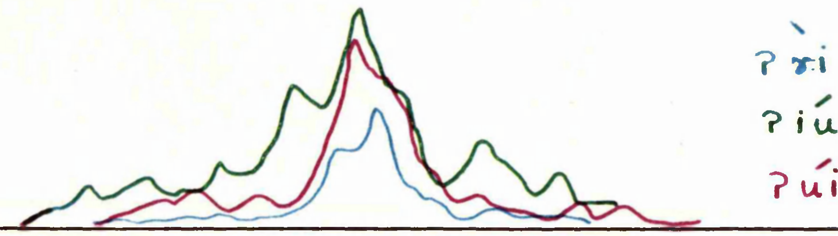


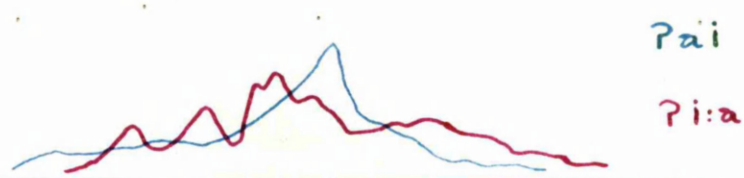


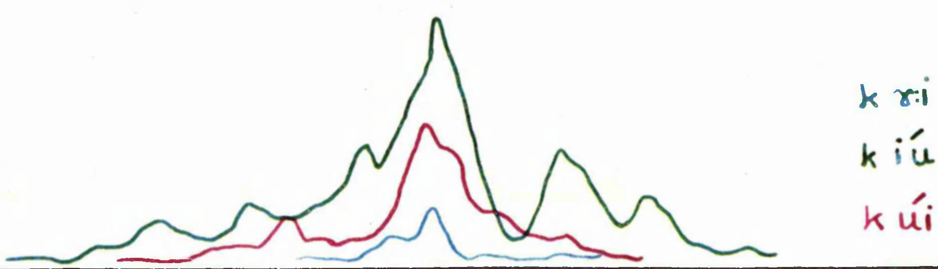


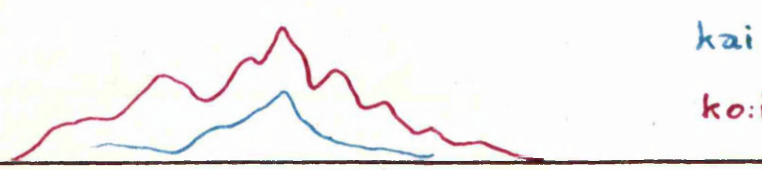


AIC XVII

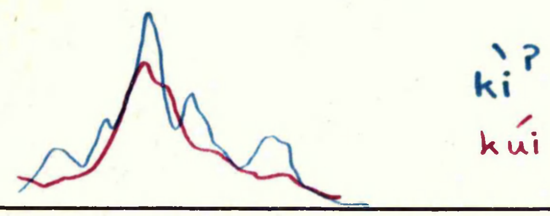


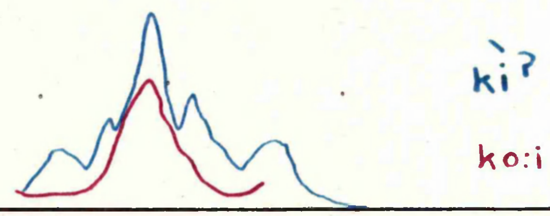


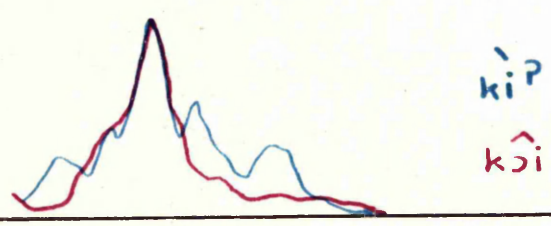


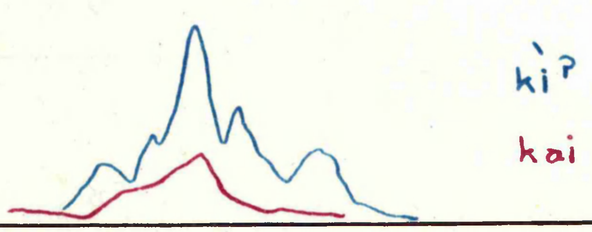


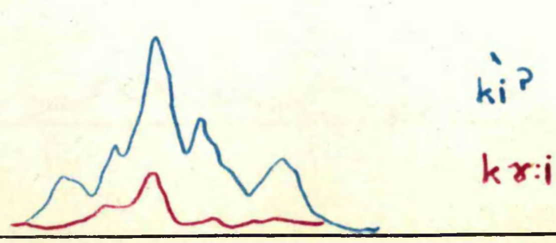
AIC XVIII



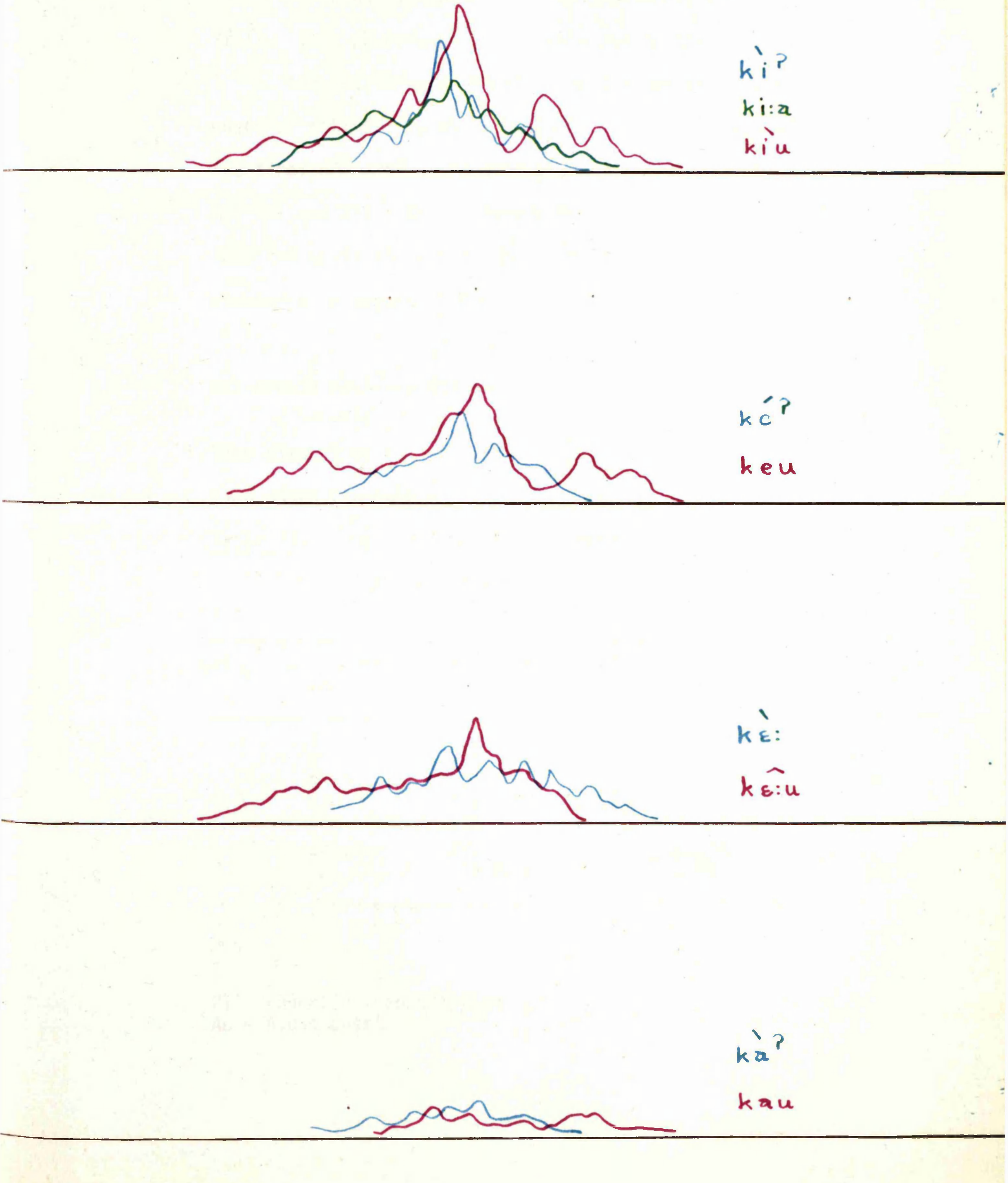








AIC XIX



either preceding or following a as well as the tension for the i following ɤ appear to be the smallest, see AIC XV and XVIII. This phenomenon is probably due to the fact that in the following or final element requires rather neutral muscular activation, while in [eu] , [ɛu] , [ɛ:u] and [ɪu] the final elements do require greater muscular activity, see AIC XVI and XIX. This evidence suggests that the commands from the brain are rather those of syllable nature type the phonemically segmental type.

DLI muscle activity for triphthongs.

Time dimension

Time onset (in msec.)

Table 14a DLI anticipation for spreading gesture in triphthongs. (five utterances)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	230		1	202
	2	235		2	200
	3	135		3	230
ʔiâu	4	232	kiâu	4	196
	5	175		5	205
	average	201		average	207
	SD	39.97		SD	12.06

PT = Phonetic Transcription
Ao = Audio onset

Table 14b. DLI time-lag for spreading gesture in triphthongs. (five utterances)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	-200		1	-165
	2	-210		2	-208
	3	-250		3	-204
?uai	4	-170	kûai	4	-164
	5	-190		5	-200
	average	-204		average	-188.2
	SD	26.53		SD	19.52
	1	- 60		1	- 20
	2	- 35		2	- 28
	3	-160		3	-165
?ɯai	4	-128	kɯai	4	-200
	5	- 70		5	- 30
	average	- 90		average	- 87
	SD	46.19		SD	77.53

PT = Phonetic Transcription
Ao = Audio onset
- mark indicates EMG onset began after Audio onset.

Comments on Tables 14a and 14b .

Anticipations for the i in[iau]syllables are of the same type as that occurring in diphthongs [i:a],[iu]. In [uai]movements of the DLI are more delayed than in the diphthong, [o:i]syllable. In the [ai]the muscular activity begins earlier than in the [uai]. This corresponds with previous electromyographic research on speech which suggested that a muscle begins to activate as soon as it is free (Lubker et al, 1975).

The SD figure of[kɯai]is rather high which indicates that time onset of this syllable considerably greatly varies. This event may due to the fact that the [kɯai]syllable is meaningless.

The DLI muscle activity for the triphthongs.

Time Dimension:

Duration (in msec.)

Table 15 DLI duration for spreading gesture in triphthongs (five utterances)

PT	utterance order	EMG duration	PT	utterance order	EMG duration
	1	300		1	340
	2	350		2	365
	3	325		3	435
?iâu	4	385	kiâu	4	350
	5	360		5	390
	average	344		average	376
	SD	29.22		SD	33.97
	1	120		1	90
	2	180		2	110
	3	205		3	155
	4	180		4	180
?uai	5	145	kuâi	5	165
	average	166		average	140
	SD	29.90		SD	34.20
	1	240		1	385
	2	255		2	290
	3	170		3	295
?ɯai	4	230	kɯai	4	230
	5	266		5	280
	average	232		average	296
	SD	33.45		SD	50.14

Comments on Table 15

The duration of DLI activity in the initial spreading in [iau] is some what between that of the long and the short monophthongs,[i:] and [i]. The durations of the final close element, even though varying, are shorter than that of the short front monophthongs. By comparing the averaged durations of the DLI action potentials of the front vowels, the results can be categorized into two groups: group one includes front vowels with a duration of 300 msecs, upwards. This group includes both long and short monophthongs as well as some diphthongs and triphthong [iau]. Group two includes only diphthongs and triphthongs.

GROUP ONE

	?		k	
i:	495	msec.	383	msec.
i:a	454		440	
iau	344		326	
i	340		342	
e:	473		463	
e	300		350	
ɛ:	360		440	
ɛ	305		309	
ɛ:u	-		332	

GROUP TWO

	?		k	
iu	239	msec.	239	msec.
eu	259		288	
ɯai	232		296	
ɛu	96		-	
uai	166		140	
ui	177		143	
ai	116		141	
ɔi	153		123	
o:i	97		100	
ɤ:i	95		120	

Intensity dimension of DLI muscle activity.

In this dimension the DLI averaged integrated curves of triphthongs containing an i element were compared among themselves and among diphthongs. (see AIC XX-XXII)

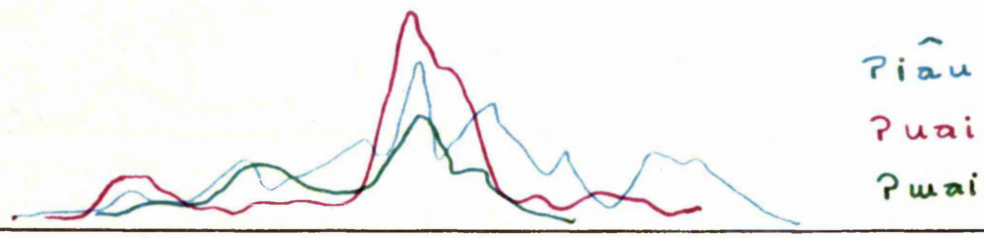
Comments on AIC XX-XXII.

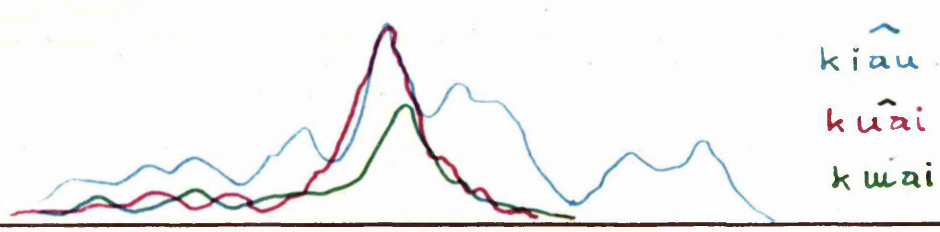
There is evidence from the syllables preceded by the [k] that the muscular tension for the initial i is greater than for the final i; however, the evidence from the syllables preceded by the [?] is not so convincing.

When the averaged integrated curves were compared between the triphthongs and the diphthongs: [?iâu], [?i:a]; [?iâu], [?iú]; [kiâu], [kìu]; and [kiâu], [ki:a], DLI muscular tensions appear to be in the following order, from the higher tension downwards: [iu], [iau], and [i:a]. On the other hand, the triphthong initiated with rounding gesture, has the highest tension when comparisons of the averaged integrated curves of the final phase were carried out. The muscular tensions for this series are: [uai], [ui], [ɤ:i], [ai], from the greater to the smaller degrees respectively.

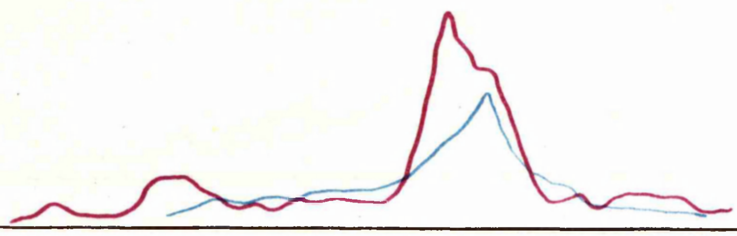
AIC XX

AIC XX

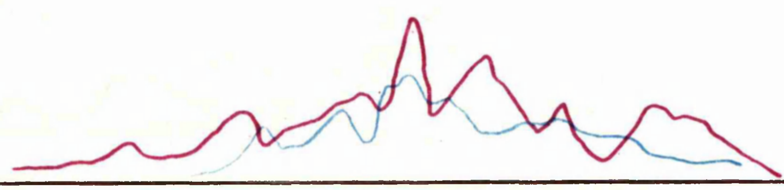




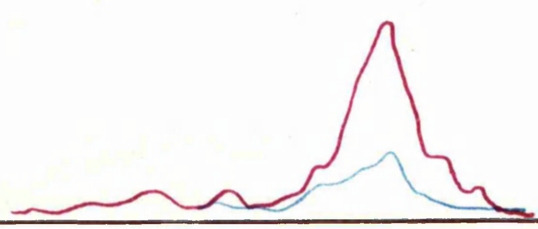
AIC XXI



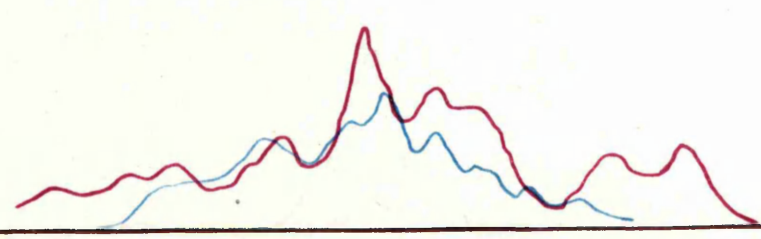
ʔai
ʔuai



ʔi:a
ʔiâu

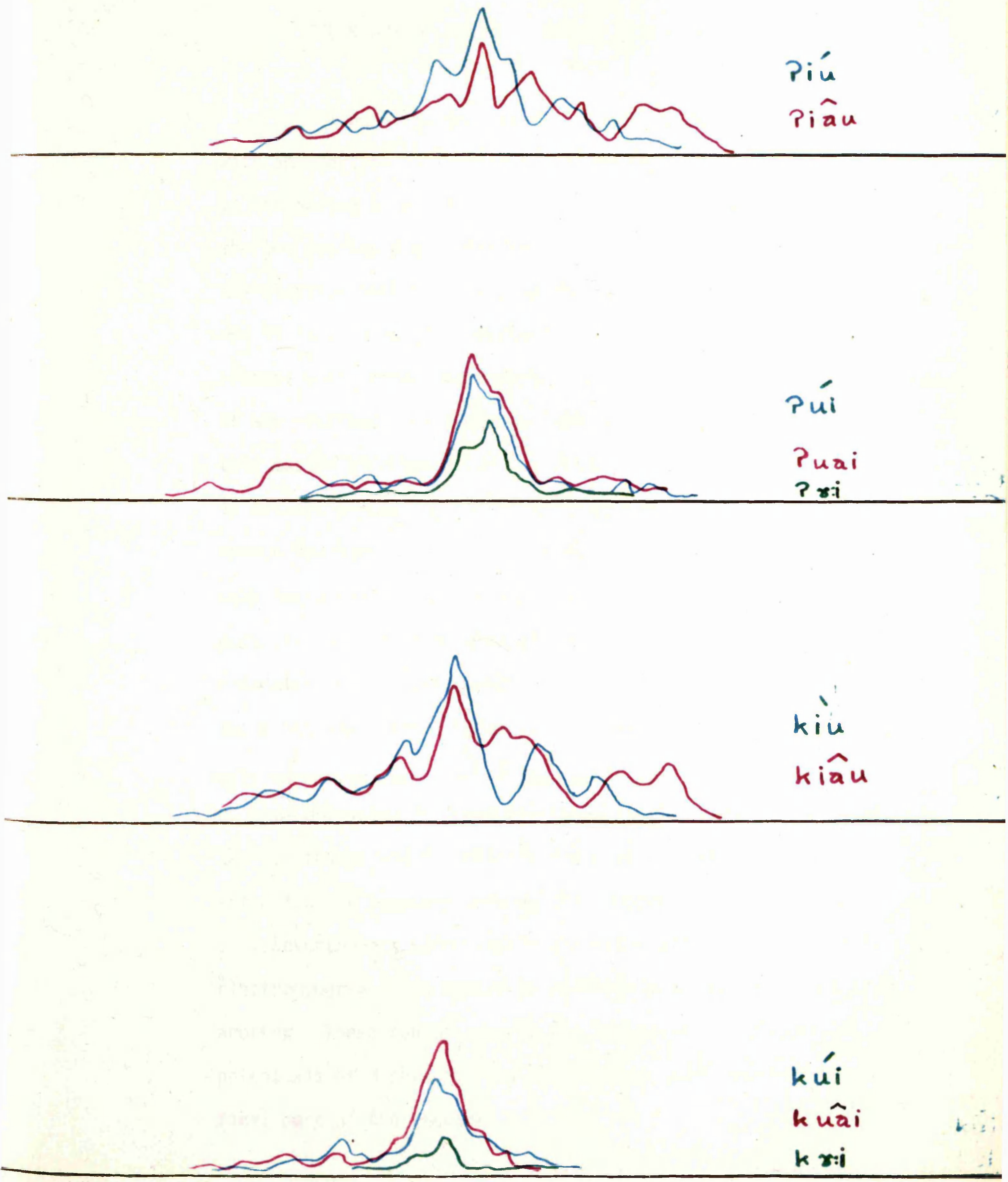


kai
kuâi



ki:a
kiâu

AIC XXII



CHAPTER 7

THE STUDY OF MENTALIS MUSCLE ACTIVITY

Generally, this muscle is said to be associated with an everting gesture of the lower lip. Due, presumably, to its having a less interesting articulatory function than the two muscles dealt with in the preceding chapters, hardly any electromyographic evidence from this muscle has been presented and it is very rarely discussed in the literature. In the present work, after the investigation on this muscle was accomplished, it was realized that there was not only muscular activity of this muscle associated with rounding gesture, but also activity in connection with spreading gesture. Thus, in this chapter speech function of the mentalis includes muscular activity in both these opposite gestures. The action potential figures occurring in the production of monophthongs will normally be presented in the same manner as in the previous chapters. For the electromyographic potentials of diphthongs and triphthongs, only intensity dimension of the muscle with be presented. No time dimension is presented since in the electromyograms of the diphthongs and triphthongs there is no convincing way to establish any boundary between the component elements. There are, nevertheless, discernible characteristics of the mentalis electromyogram which appear to differentiate one component from another. These can be seen in the traces of the EMG action potentials of diphthongs and triphthongs, (presented in the final part of the chapter).

Mentalis muscle activity for monophthongs.

Time dimension.

Time onset (in msec.)

Table 16. Mentalis anticipation for monophthongs

(five utterances)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	220		1	210
	2	165		2	230
	3	200		3	175
?ì:	4	120	kì:	4	160
	5	238		5	178
	average	189		average	190
	SD	42		SD	25.56
	1	250		1	135
	2	180		2	155
	3	180		3	110
?ì?	4	165	kì?	4	220
	5	203		5	80
	average	196		average	140
	SD	29.80		SD	47.22
	1	200		1	135
	2	300		2	155
	3	124		3	110
?é:	4	210	ké:	4	220
	5	300		5	80
	average	227		average	140
	SD	66.76		SD	47.22
	1	280		1	220
	2	190		2	205
	3	105		3	187
?é?	4	280	ké?	4	190
	5	285		5	190
	average	228		average	198
	SD	71.03		SD	12.50

Table 16 (cont.)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
	1	275		1	210
	2	160		2	247
	3	148		3	205
ʔɛ̂:	4	155	kɛ̀:	4	215
	5	145		5	150
	average	177		average	205
	SD	49.48		SD	31.35
	1	232		1	180
	2	190		2	185
	3	117		3	155
ʔɛ́ʔ	4	95	kɛ́ʔ	4	200
	5	195		5	148
	average	166		average	174
	SD	51.40		SD	19.33
	1	260		1	55
	2	175		2	75
	3	170		3	155
ʔɔ̌:	4	152	kɔ̀:	4	68
	5	185		5	85
	average	188		average	88
	SD	37.36		SD	35.08
	1	250		1	140
	2	188		2	90
	3	205		3	140
ʔɔ̀ʔ	4	160	kɔ̀ʔ	4	98
	5	190		5	122
	average	199		average	118
	SD	29.52		SD	33.96
	1	200		1	200
	2	192		2	189
	3	200		3	155
ʔò:	4	180	kô:	4	117
	5	238		5	120
	average	202		average	156
	SD	19.43		SD	34.18
	1	300		1	244
	2	200		2	220
	3	315		3	192
ʔóʔ	4	195	kóʔ	4	176
	5	210		5	205
	average	244		average	207
	SD	52.28		SD	23.35

Table 16 (cont.)

PT	utterance order	EMG onset to Ao	PT	utterance order	EMG onset to Ao
?ù:	1	245	kù:	1	365
	2	290		2	170
	3	180		3	160
	4	160		4	192
	5	250		5	235
	average	225		average	224
	SD	47.95		SD	74.88
?ù?	1	330	kù?	1	304
	2	250		2	96
	3	195		3	210
	4	180		4	200
	5	250		5	218
	average	241		average	206
	SD	52.76		SD	66.18

Comments on Table 16.

The pattern of time onset of the mentalis electromyograms, though occurring prior to the acoustic onset, is not quite the same as those of the OOI and the DLI onsets. Apparently, there is no regular pattern whereby the time onset of the short vowels is earlier than that of the long ones. Either SD figures indicate no regular pattern of variation. That is high and low variation occurred in the productions of both front and back vowels.

Mentalis muscle activity for monophthongs.

Time dimension

Duration (in msec)

Table 17 Mentalis duration for monophthogns

(five utterance)

PT	utterance order	EMG duration	PT	utterance order	EMG duration
	1	470		1	518
	2	435		2	462
	3	490		3	422
?ì:	4	390	kì:	4	370
	5	490		5	360
	average	455		average	426
	SD	38.20		SD	58.76
	1	345		1	300
	2	245		2	255
	3	265		3	275
?ì?	4	280	kì?	4	294
	5	325		5	290
	average	292		average	283
	SD	37.36		SD	16.16
	1	440		1	380
	2	505		2	480
	3	410		3	350
?é:	4	450	ké:	4	425
	5	525		5	327
	average	466		average	392
	SD	42.59		SD	54.70
	1	450		1	315
	2	290		2	340
	3	250		3	310
?é?	4	390	ké?	4	285
	5	385		5	260
	average	353		average	302
	SD	72.63		SD	27.31

Table 17. (cont.)

PT	utterance order	EMG duration	PT	utterance order	EMG duration
	1	530		1	440
	2	390		2	465
	3	425		3	425
?ɛ̂:	4	460	kɛ̂:	4	490
	5	375		5	450
	average	436		average	454
	SD	55.44		SD	22.22
	1	350		1	300
	2	290		2	310
	3	244		3	245
?ɛ́?	4	265	kɛ́?	4	280
	5	315		5	260
	average	293		average	279
	SD	37.22		SD	24.16
	1	485		1	380
	2	400		2	350
	3	357		3	350
?ɔ̌:	4	380	kɔ̀:	4	300
	5	430		5	250
	average	410		average	326
	SD	44.34		SD	45.87
	1	380		1	125
	2	270		2	210
	3	250		3	250
?ɔ̀?	4	250	kɔ̀?	4	165
	5	245		5	280
	average	279		average	206
	SD	51.22		SD	55.98
	1	585		1	450
	2	510		2	417
	3	475		3	465
?ò:	4	465	kô:	4	455
	5	500		5	420
	average	507		average	441
	SD	42.26		SD	17.65
	1	400		1	438
	2	330		2	370
?ó?	3	520	kó?	3	330
	4	300		4	280
	5	330		5	310
	average	376		average	346
	SD	79.14		SD	49.91

Table 17 . (cont.)

PT	utterance order	EMG duration	PT	utterance order	EMG duration
	1	505		1	437
	2	415		2	235
	3	360		3	340
?ù?	4	370	kù?	4	405
	5	380		5	356
	average	406		average	356
	SD	52.85		SD	63.08
	1	520		1	630
	2	615		2	430
	3	420		3	475
?ù:	4	445	kù:	4	495
	5	540		5	360
	average	508		average	480
	SD	69.75		SD	63.08

Comments on Table 17 .

There is as with the other muscles evidence that the length of EMG action potentials for a long vowel is not twice that of a short one. Generally, the durations of the syllables preceded by the [?] seems to be longer than those of the-syllables preceded by the [k] . The durational figures, however, are in reversed order in the case of [?ɛ̂:]and [kɛ̀:] syllables. The SD figures do not clearly indicate any particular characteristic of variation. There are, in general high and low variations occurred in front as well as in back vowels. Nevertheless, there is a tendency of higher variation among the articulation of [?] than the rest.

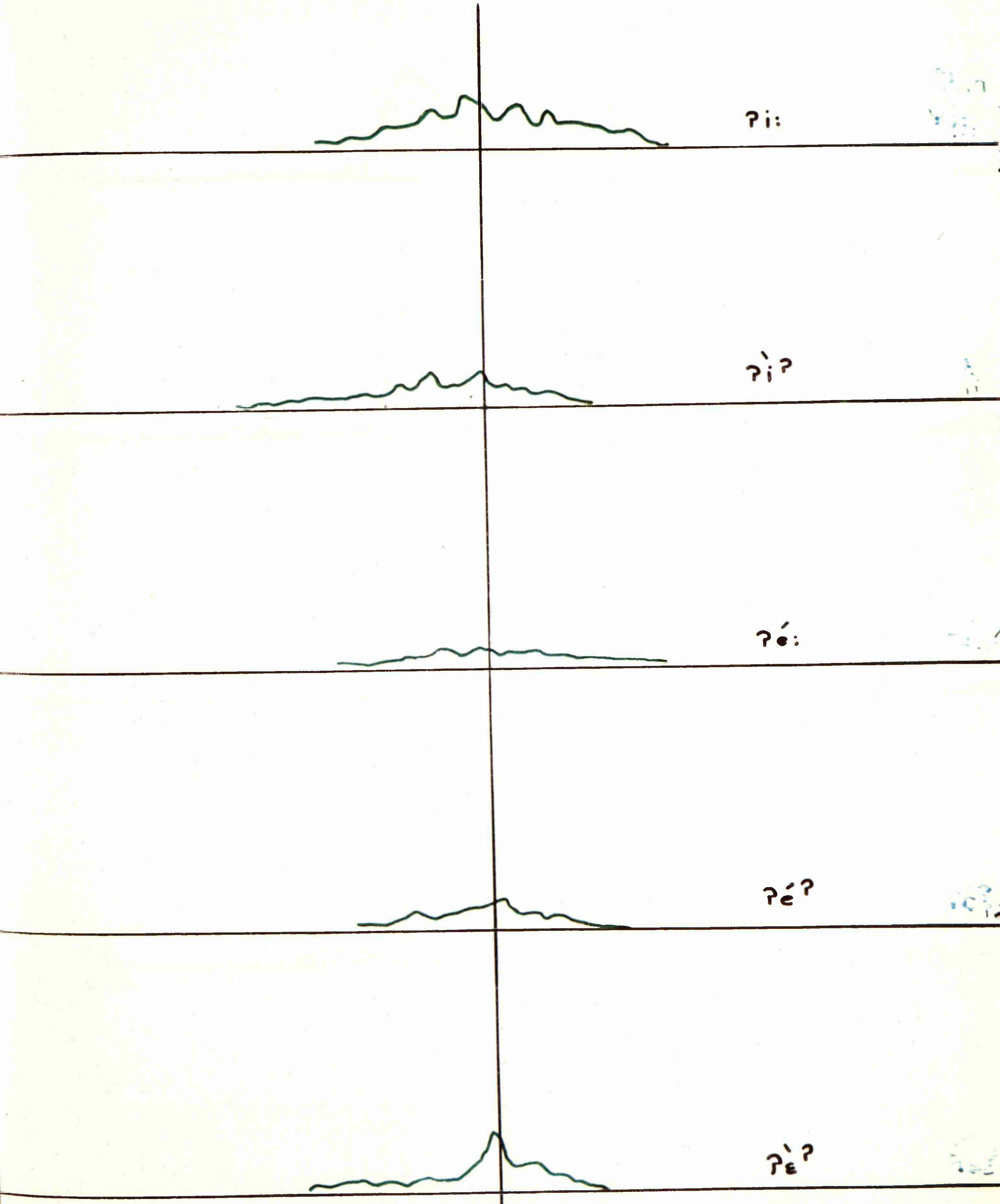
The mentalis muscle activity for monophthongs.

Intensity dimension. (see AIC XXIII-XXVII)

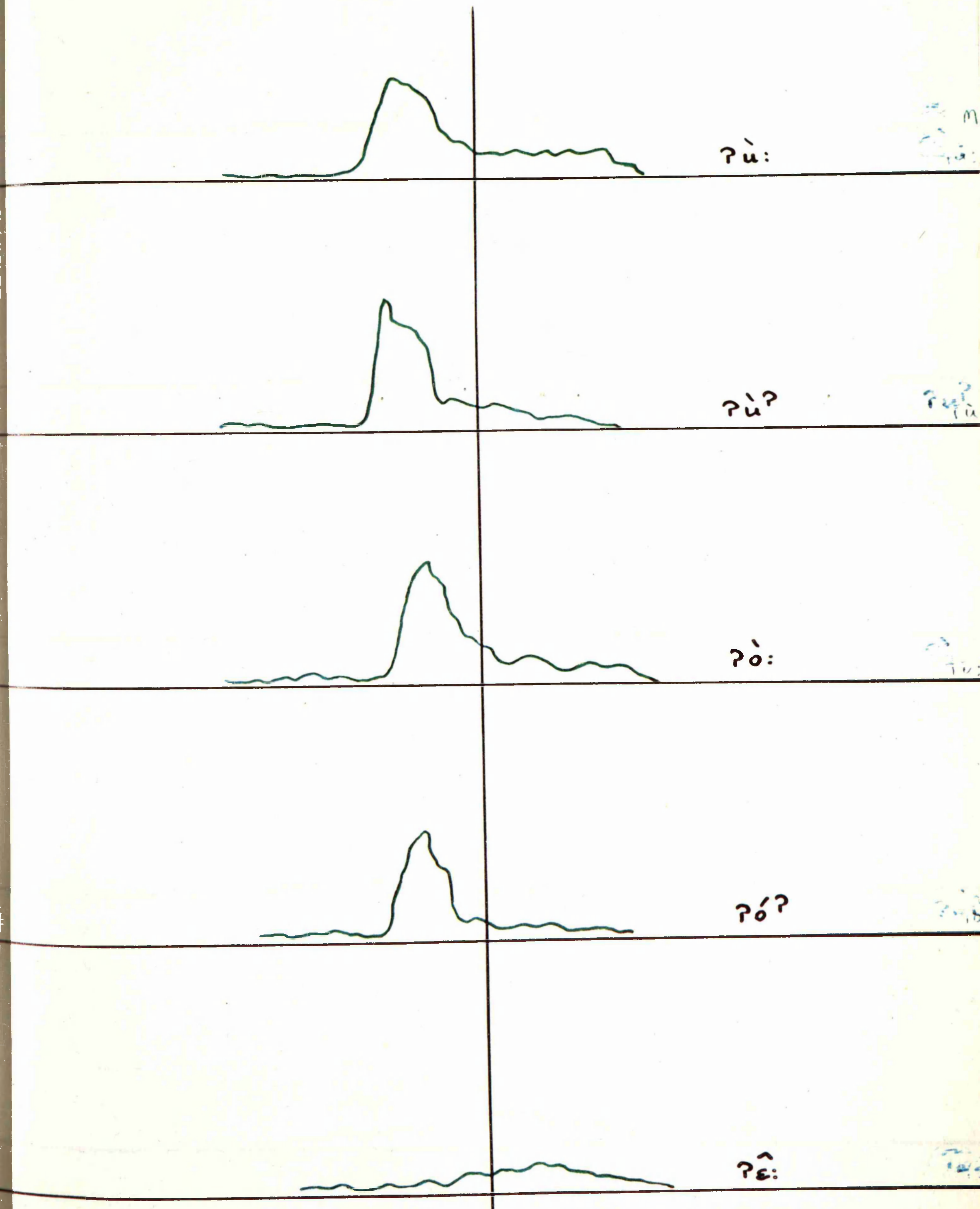
Comments on AIC XXIII-XXVII

There is unexpected evidence that the temporal muscular tension for rounding gesture is markedly less active in the syllables preceded by [k], (see AIC XXIV, XXVI and XXVII). This characteristic consistently appears throughout the series preceded by the [k]. This event may signify that the nature of motor command is not in the traditional form of phonemical string. For those syllables preceded by the [?] the activity for the rounded vowels is significantly greater than that for the unrounded ones. The integrated curves indicating rounding gesture all have relatively the same characteristic, that is sharp rising followed by rapid declining.

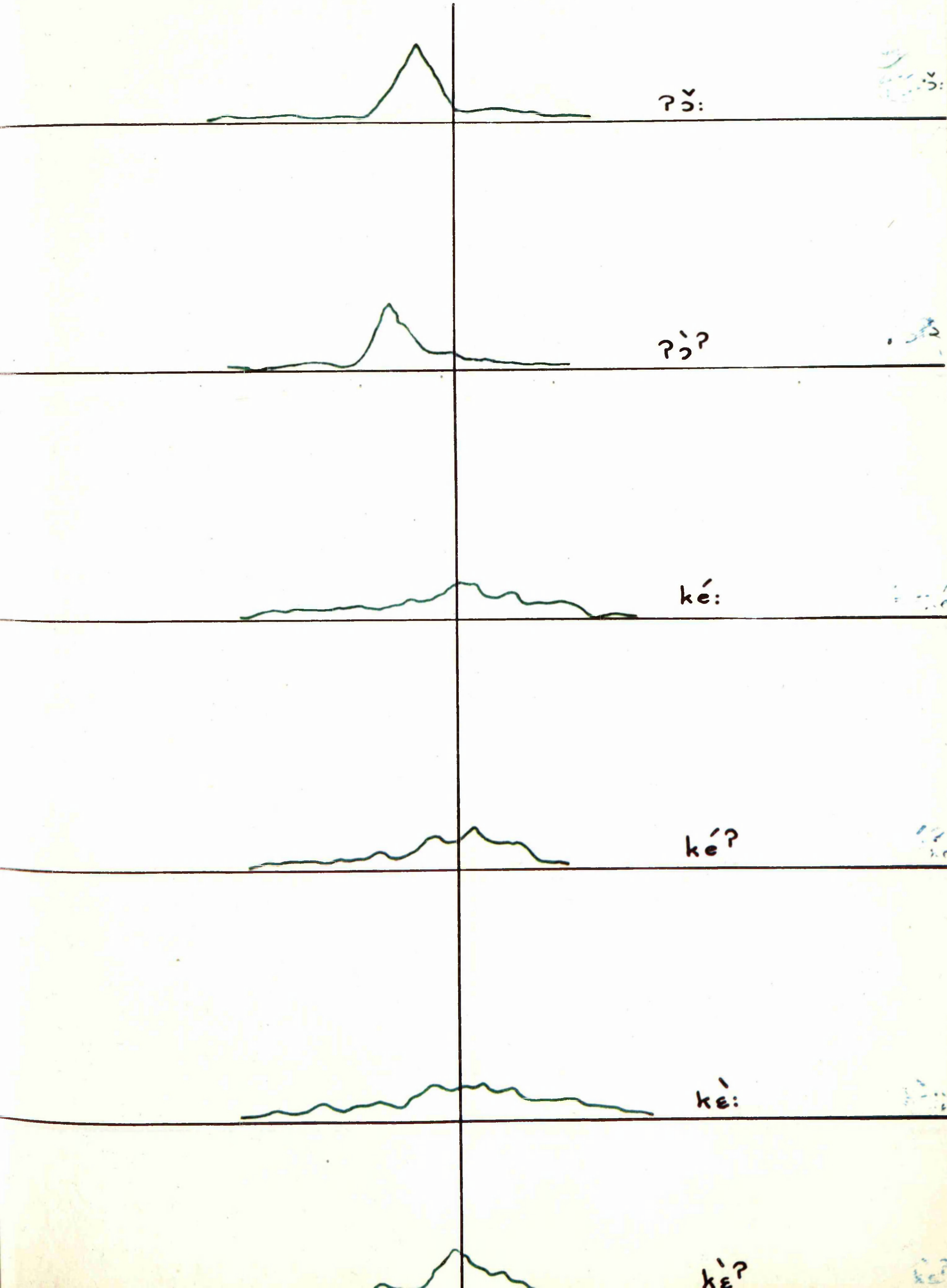
AIC XXIII



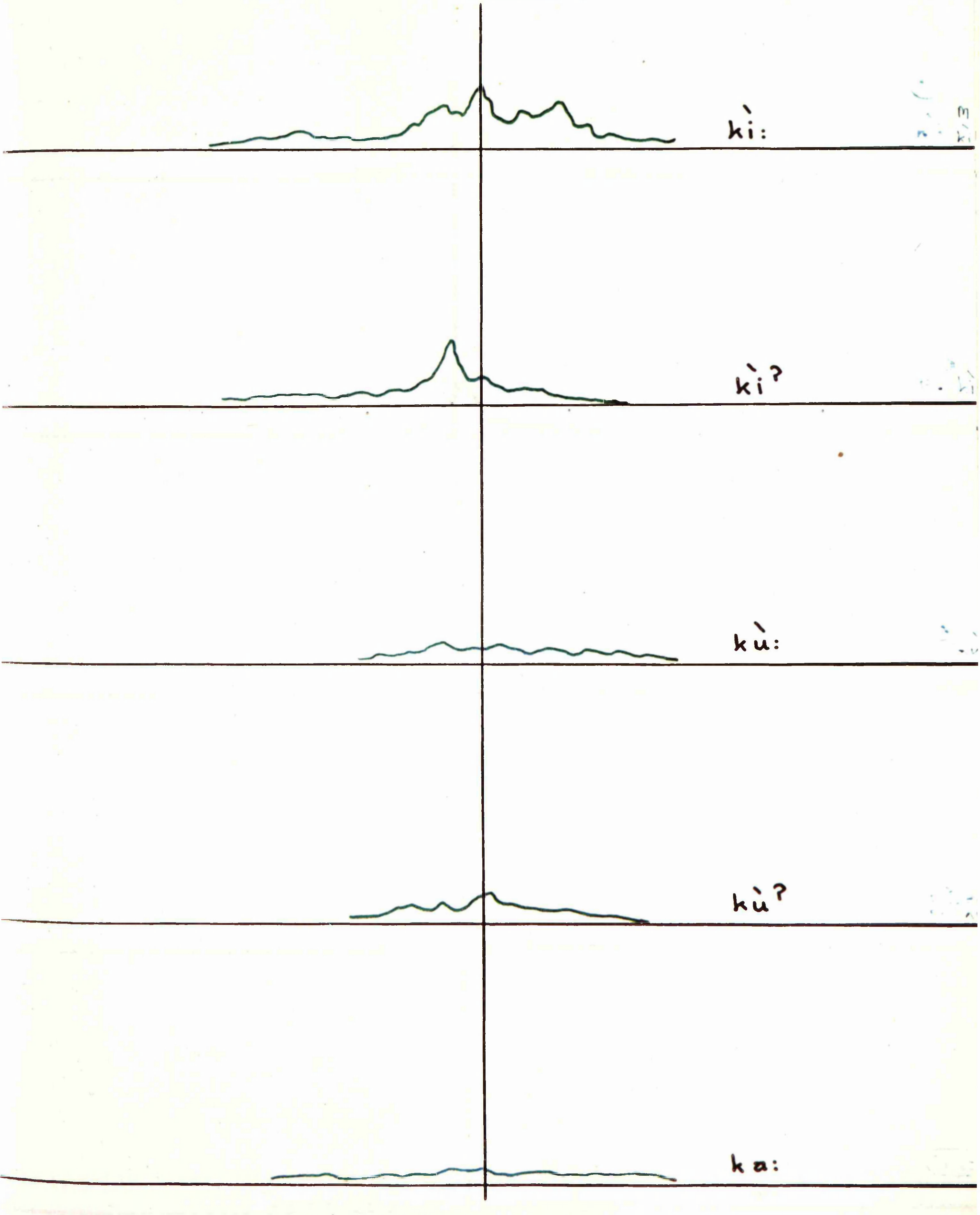
AIC XXIV



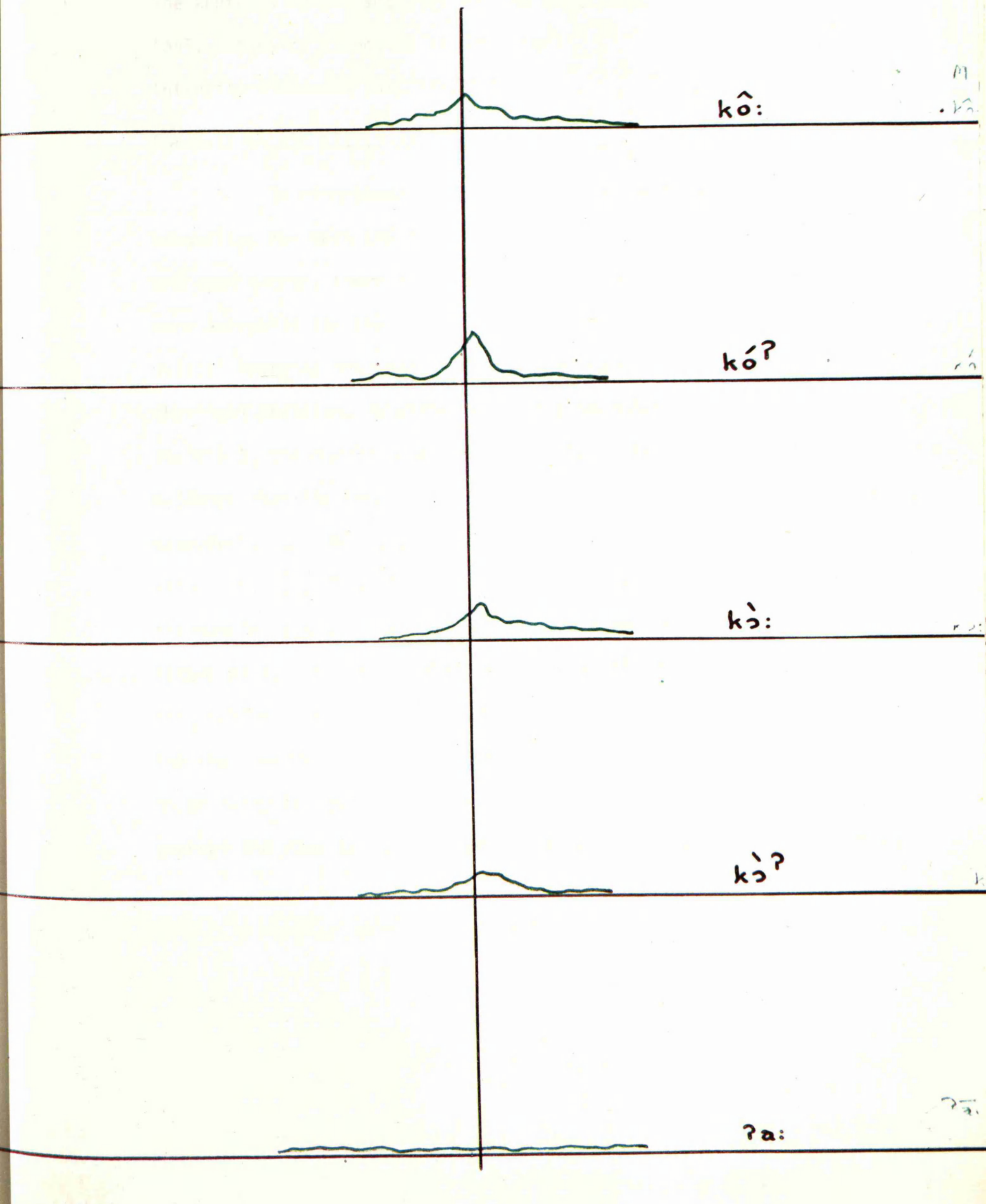
AIC XXV



AIC XXVI



AIC XXVII



The mentalis muscle activity for the diphthongs.

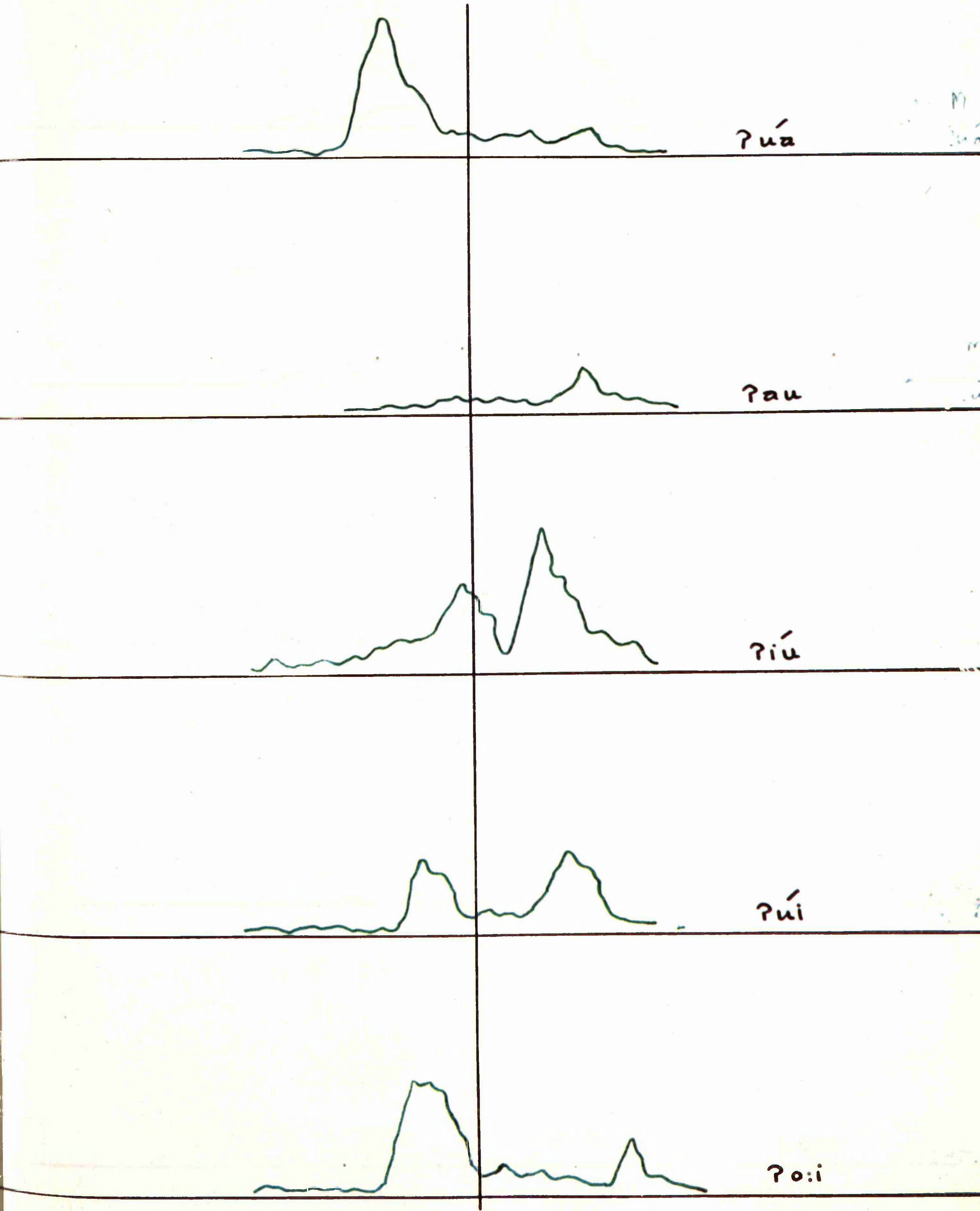
(only intensity dimension is presented)

Intensity dimension (AIC XXVIII-XXX).

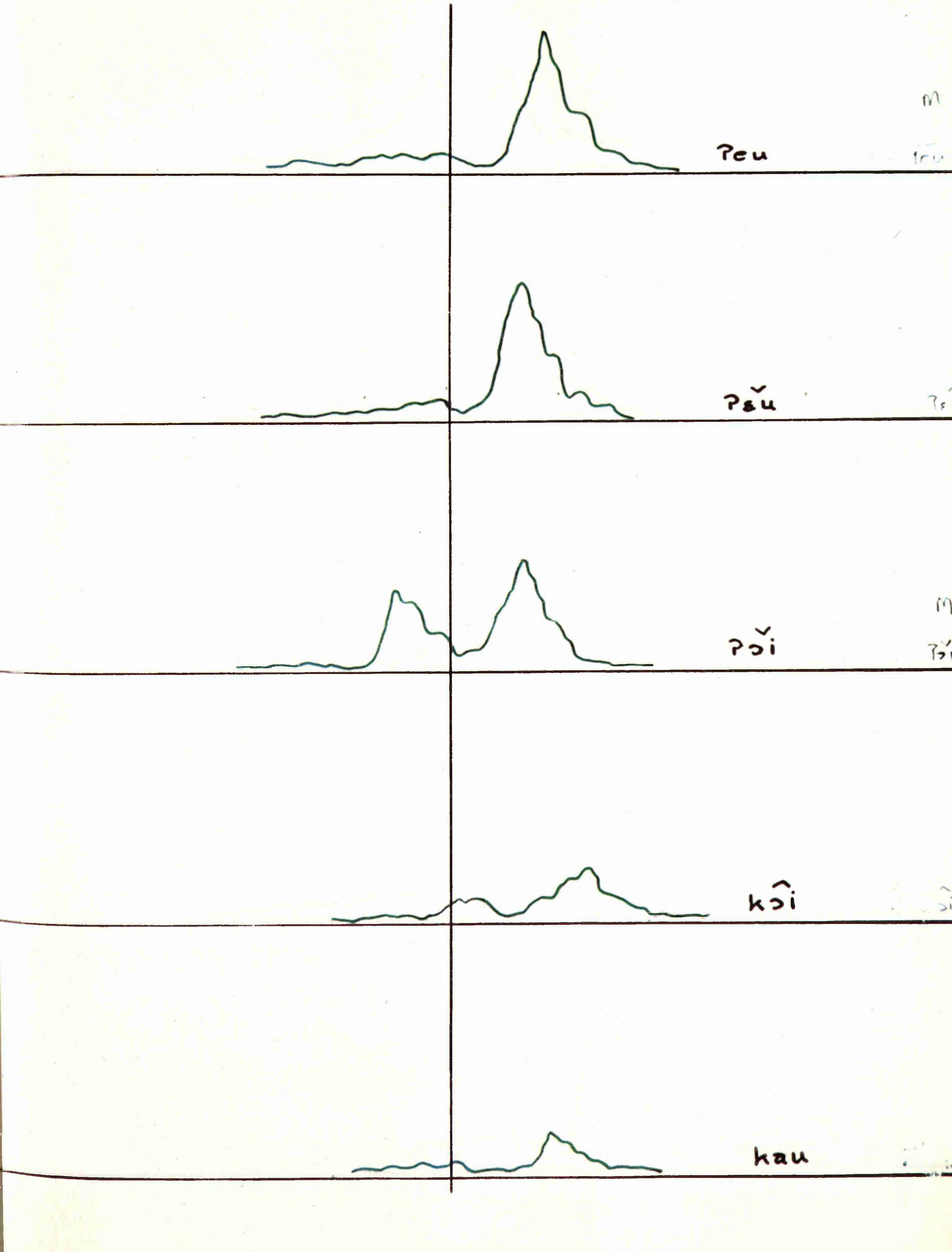
Comments on AIC XXVIII-XXX

In diphthongal utterances the muscle is active, though unequally, for both the front and the back vowels. From the traces of averaged curves, there are indications confirming that the muscle is more energetic for the initial rounding preceded by [?] than for the initial rounding preceded by [k]. When rounding gesture occurs in the final position, in either syllables preceded by the [?] or by the [k], the muscle seems to be equally active. There is also evidence that the muscular programming activity seems to be contextually dependent, for instance, in the case of [?úạ] , [?au] as compared with [?íu], [?úi] . . In the first pair, i.e. [?úa], [?au] , the muscle is active for the initial rounding component. In the latter pair, i.e. [?íu], [?úi] , the muscle is basically active for both components of each diphthong, and is actually more active for the rounding element in each case. There is a similar sharp rise in activity following the front spreading gesture in [?eu] and [?ɛ̌u], whereas the rise is less marked following the rounding gesture in [?úi].

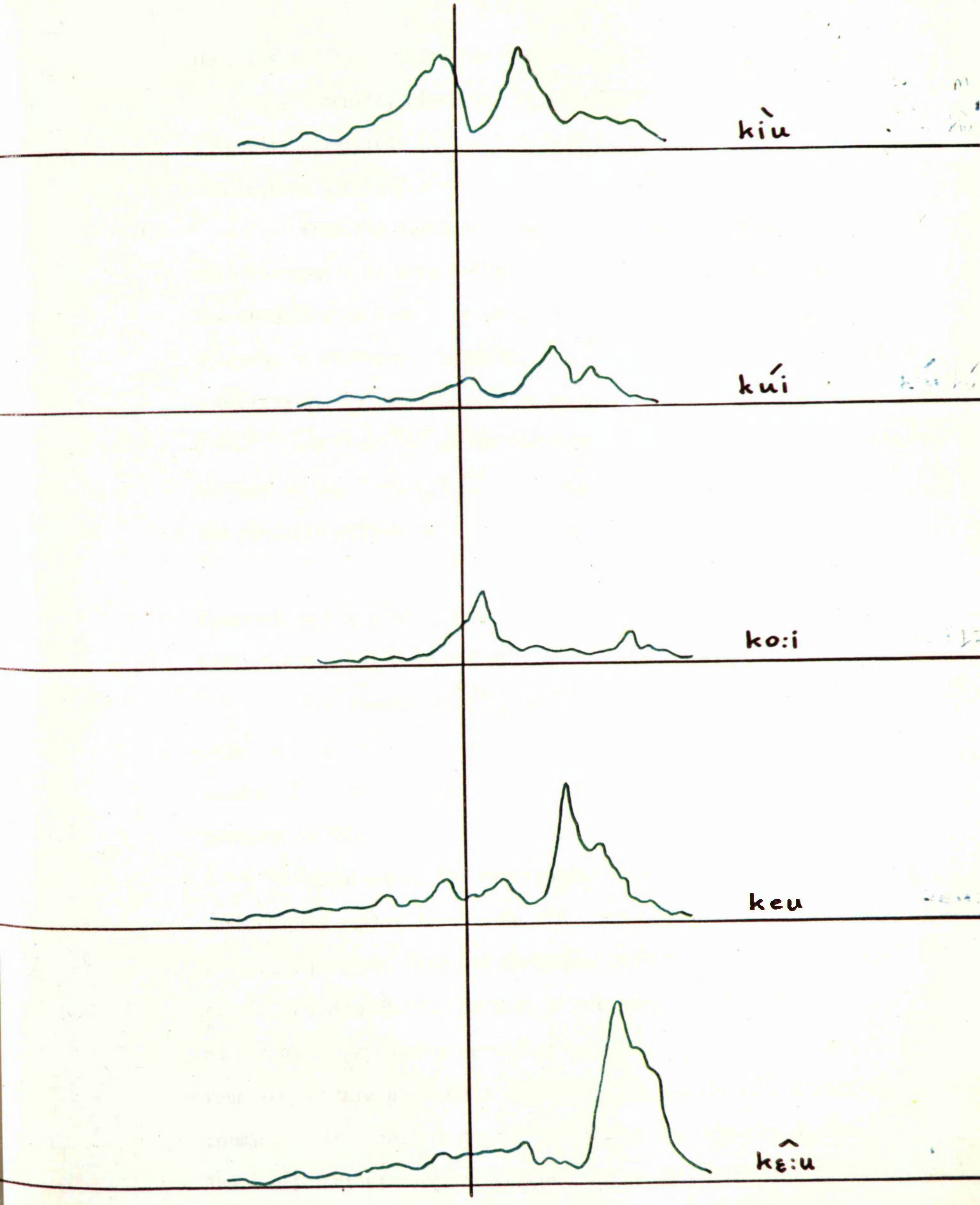
AIC XXVIII



AIC XXIX



AIC XXX



Mentalis muscle activity for triphthongs.

(only intensity dimension is presented)

Intensity dimension. (AIC XXXI-XXXII)

Comments on AIC XXXI-XXXII.

From the averaged integrated curves, it is demonstrated that the muscle is more active for the rounding gesture than for the spreading gesture. In addition, the tension for spreading postures in different contexts and positions is inconsistent. It appears that high muscular activity occurs in the syllables of [ɪau] and [uaɪ]in which contrast gestures are to be performed, whereas in [ɯaɪ] there is no contrast gesture needed so that the muscular action looks rather low.

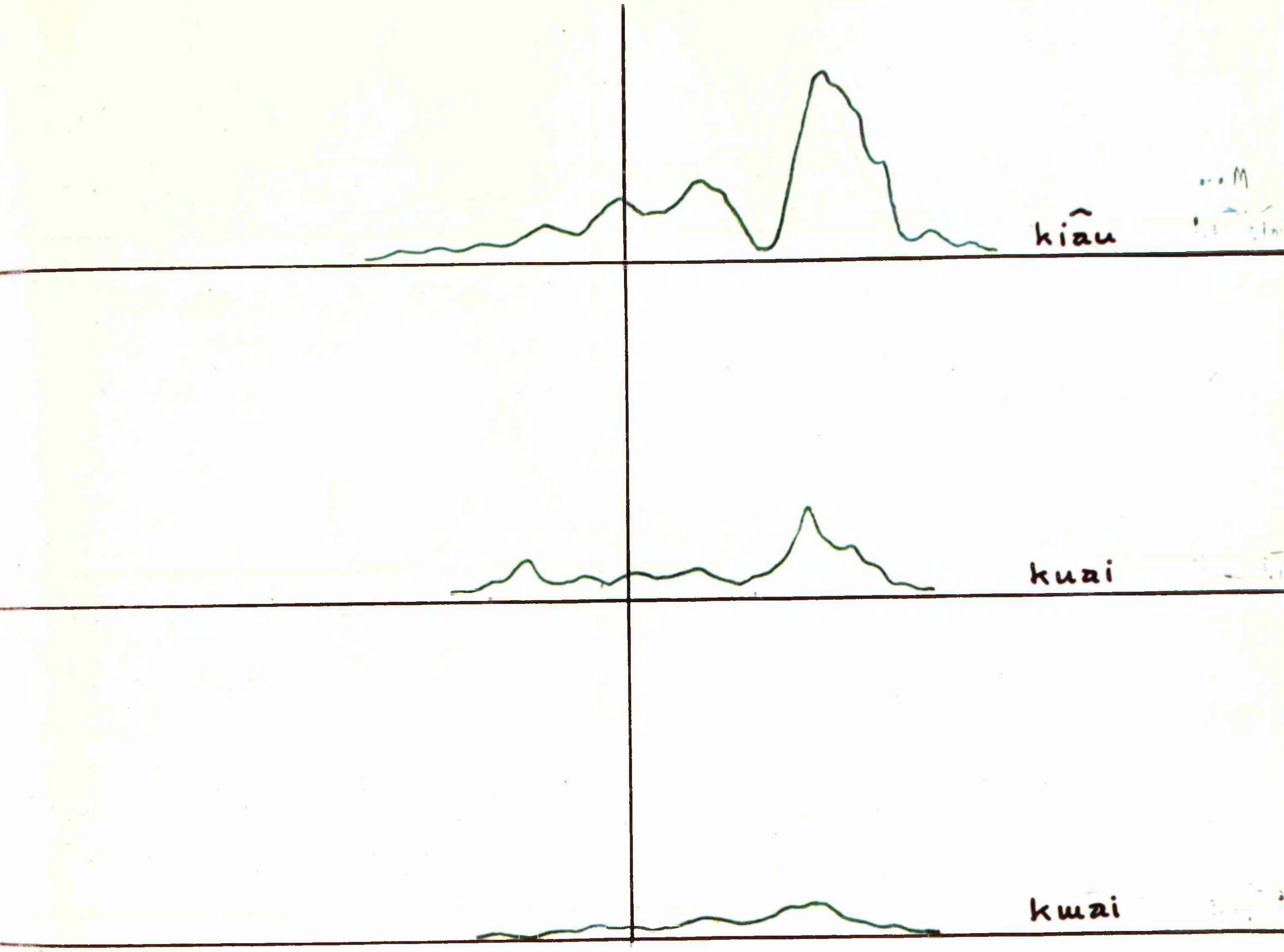
Comparative study of the characteristics of the mentalis electromyographic potentials.

One sample EMG of selected utterances is presented in order to demonstrate the EMG potential phenomena of the mentalis muscle for spreading and rounding gesture (see EMG XXVI-XL).

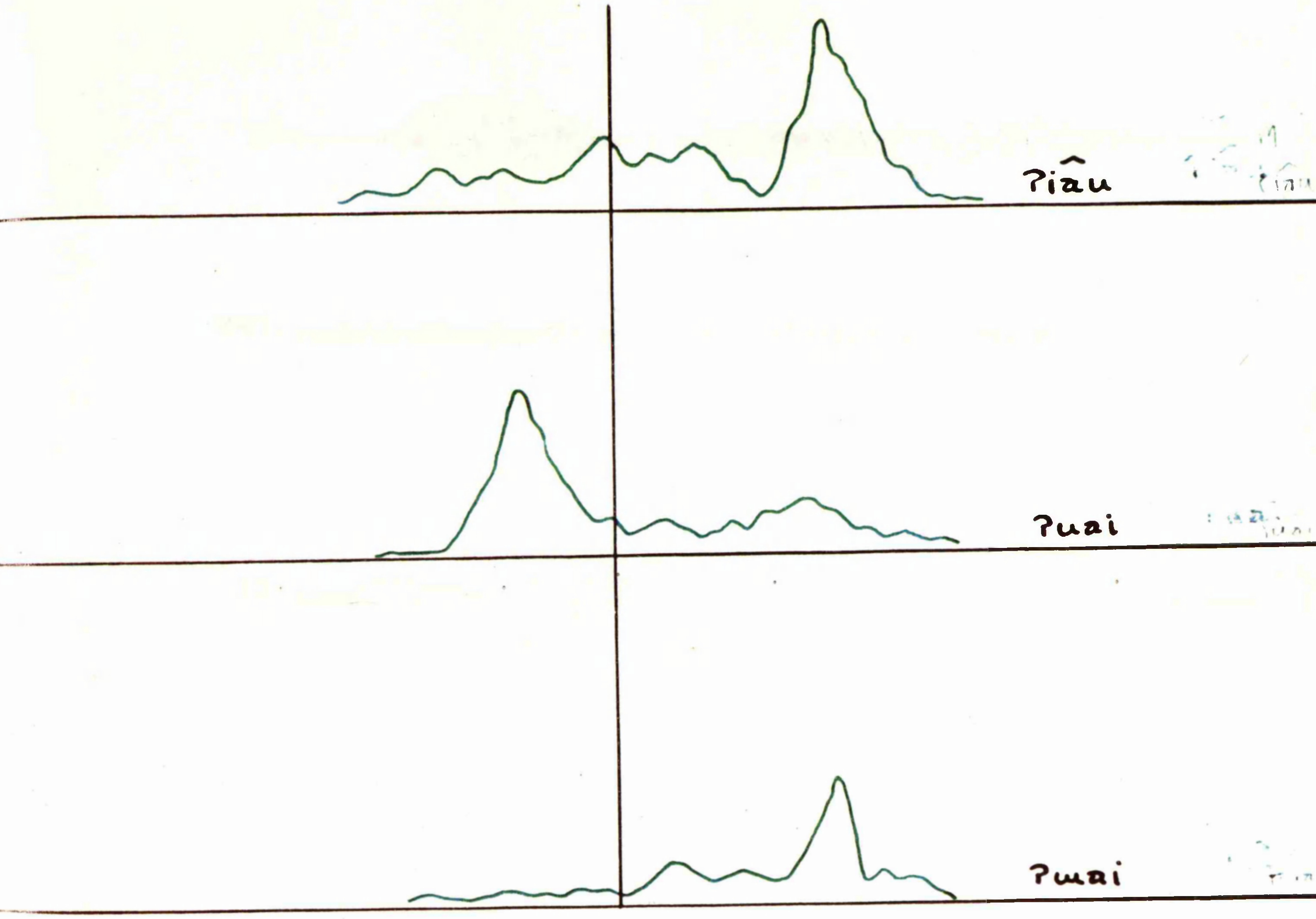
Comments on EMG XXVI-XL.

Apparently, the electromyographic potentials of spreading gestures are rather less in density than those of the roundings. It seems, perhaps, that the spreading gesture potentials are the result of antagonistic reaction of the mentalis toward the DLI muscle while performing spreading gestures. In contrast, the rounding gesture potentials seem to be the result of a direct motor command to the mentalis muscle to perform the rounding gestures. These distinctive muscular activities are not only observable in the monophthongal utterances, but also in the utterances of diphthongs and triphthongs.

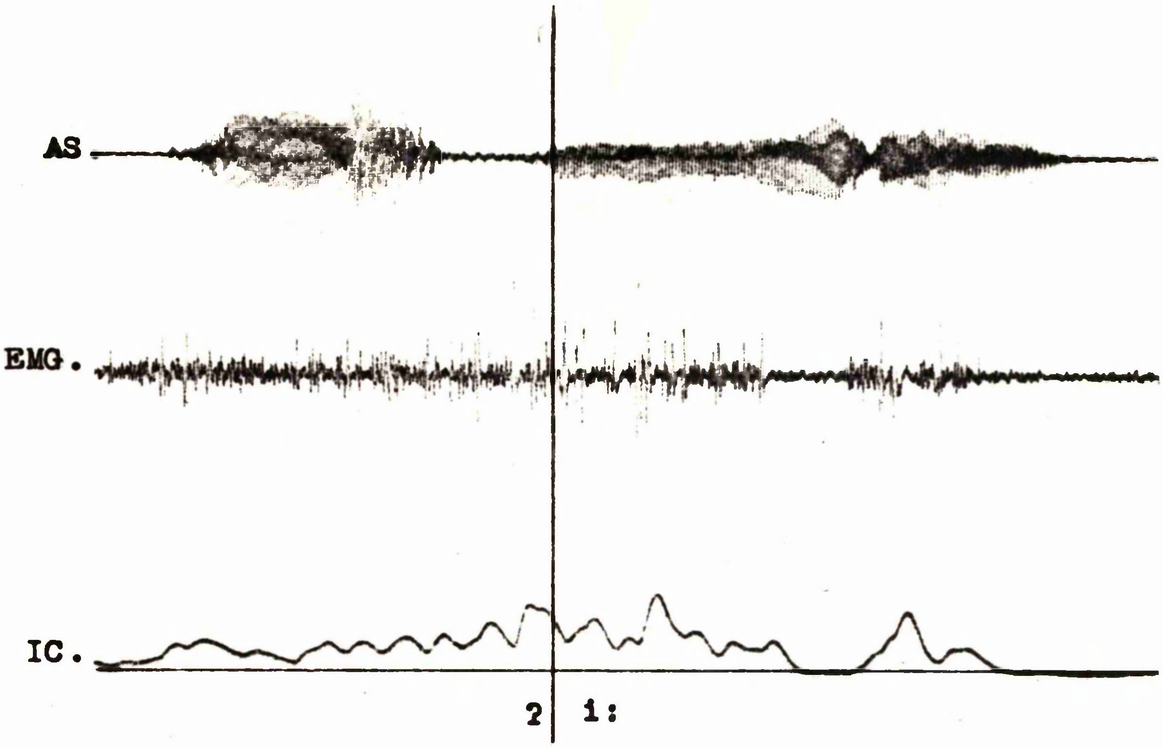
AIC XXXI



AIC XXXII



EMG XXVI



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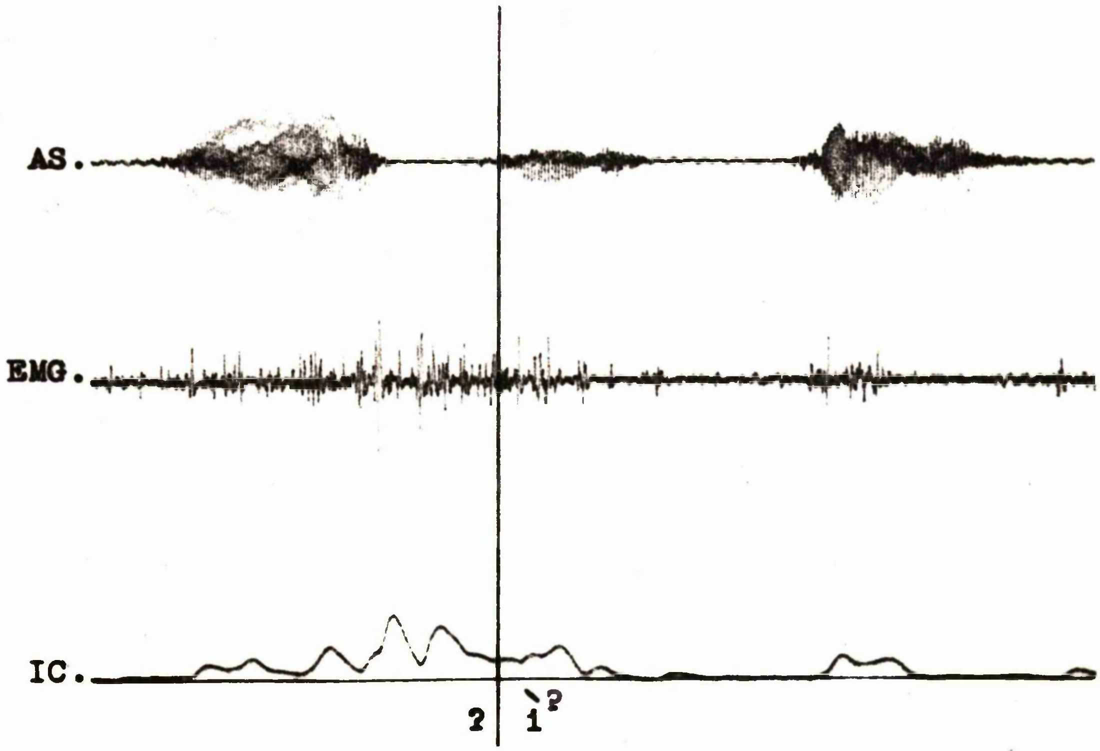
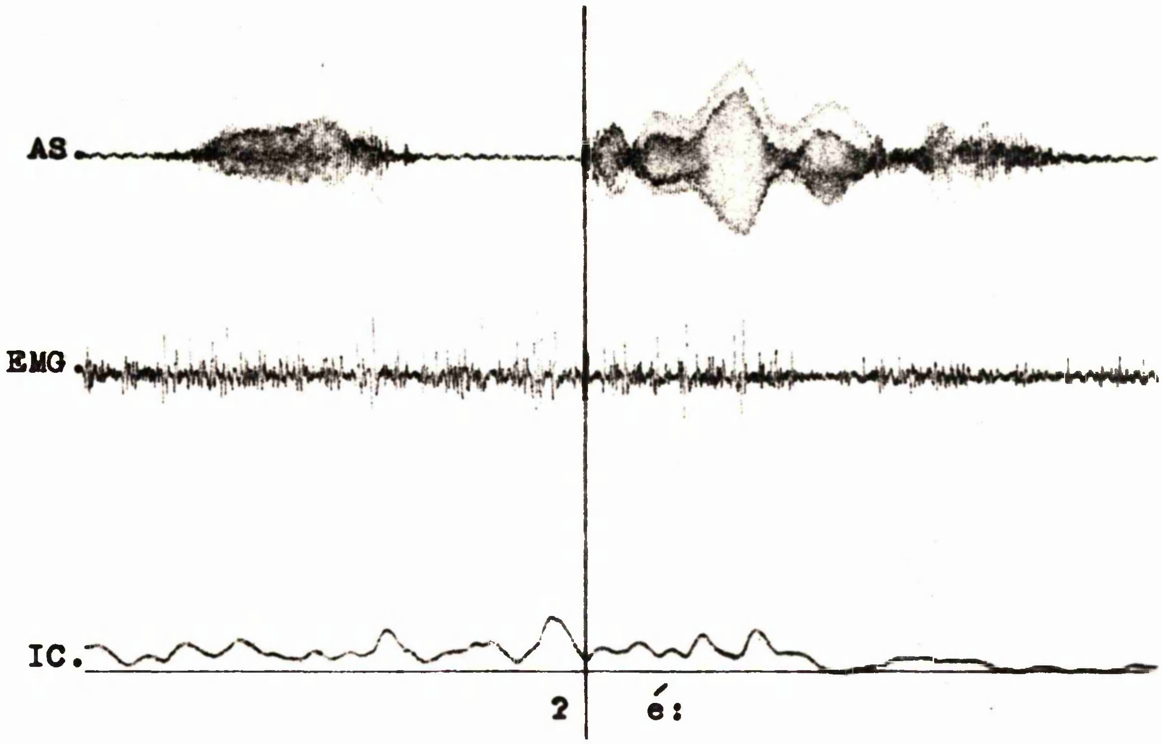


(b)

EMG XXVII



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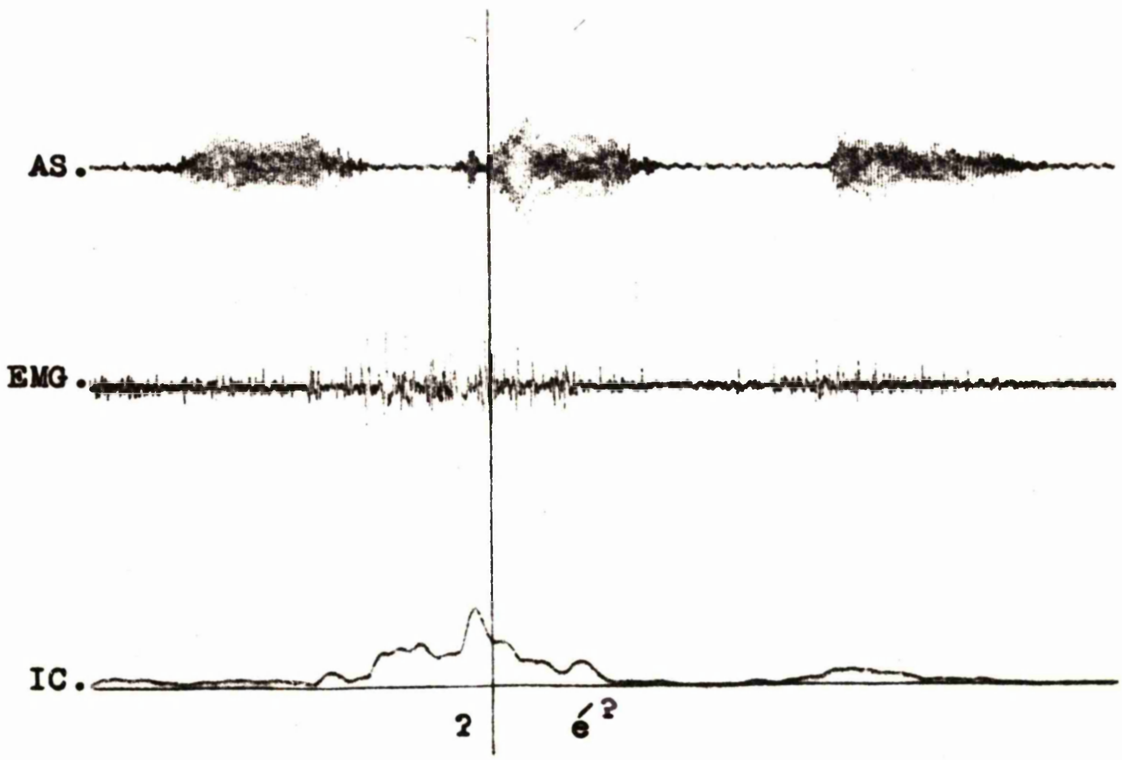

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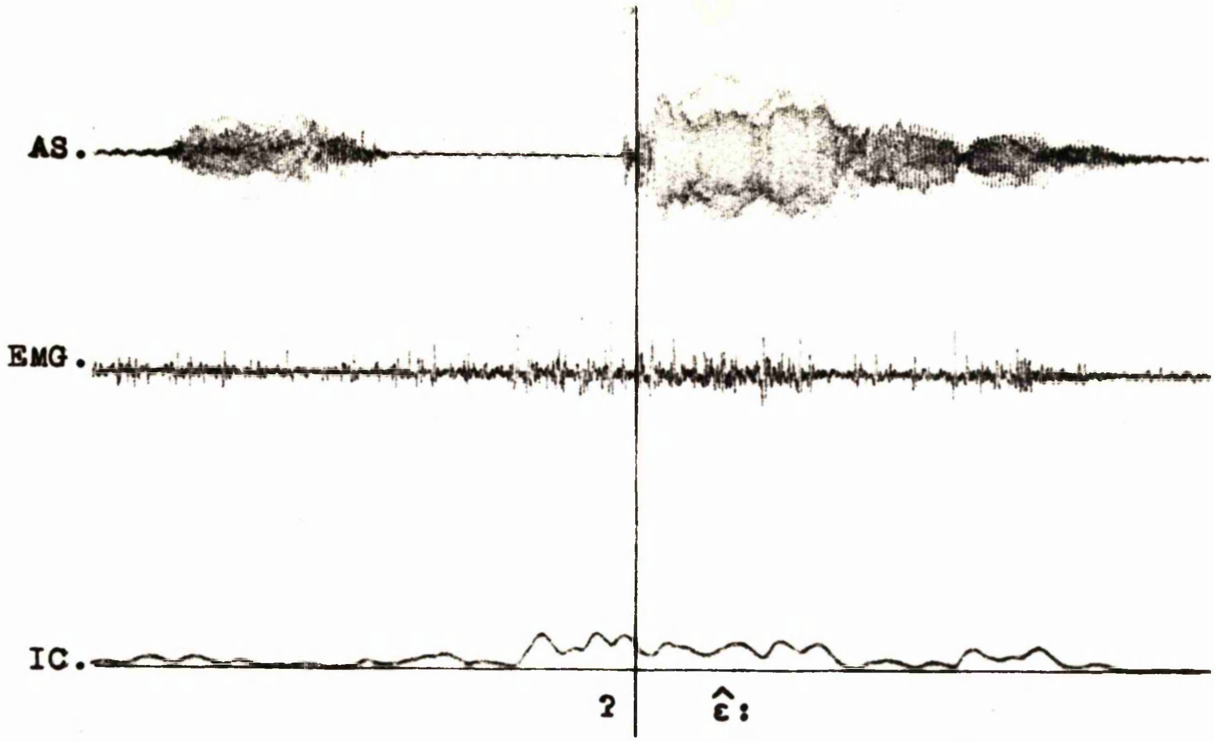
EMG XXVIII



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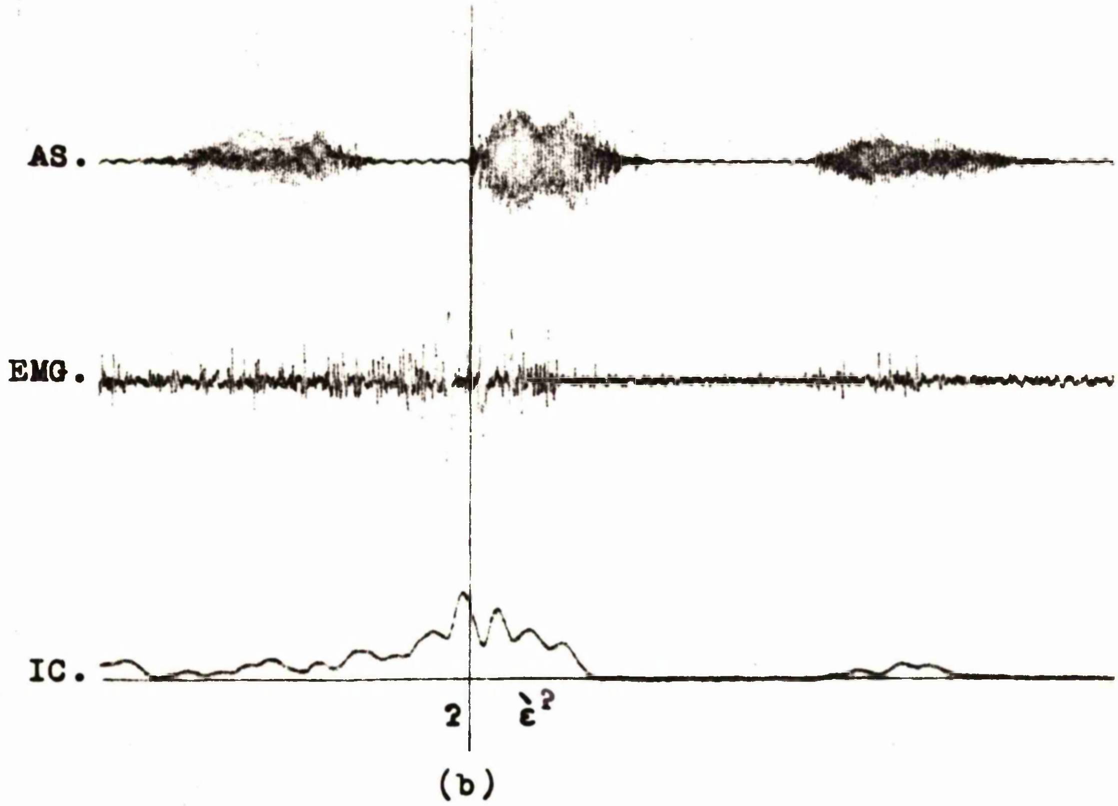

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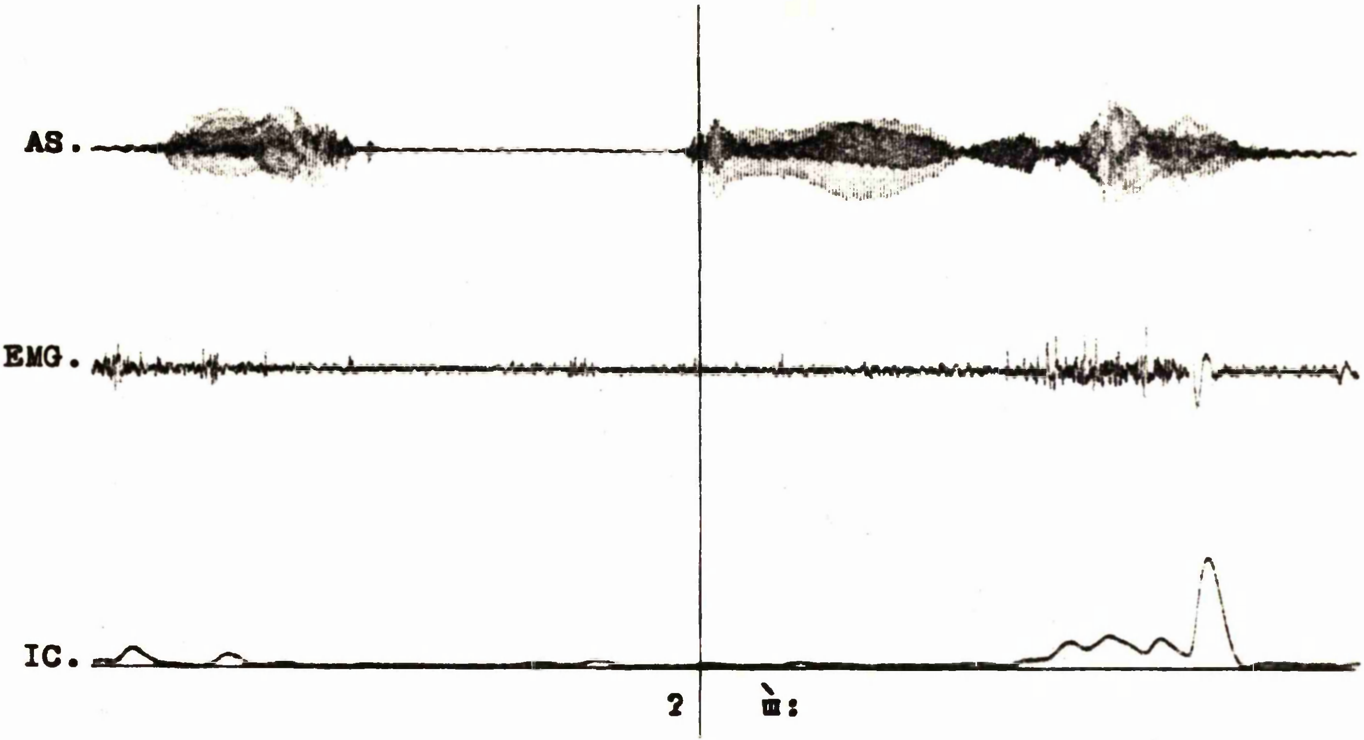
EMG XXIX



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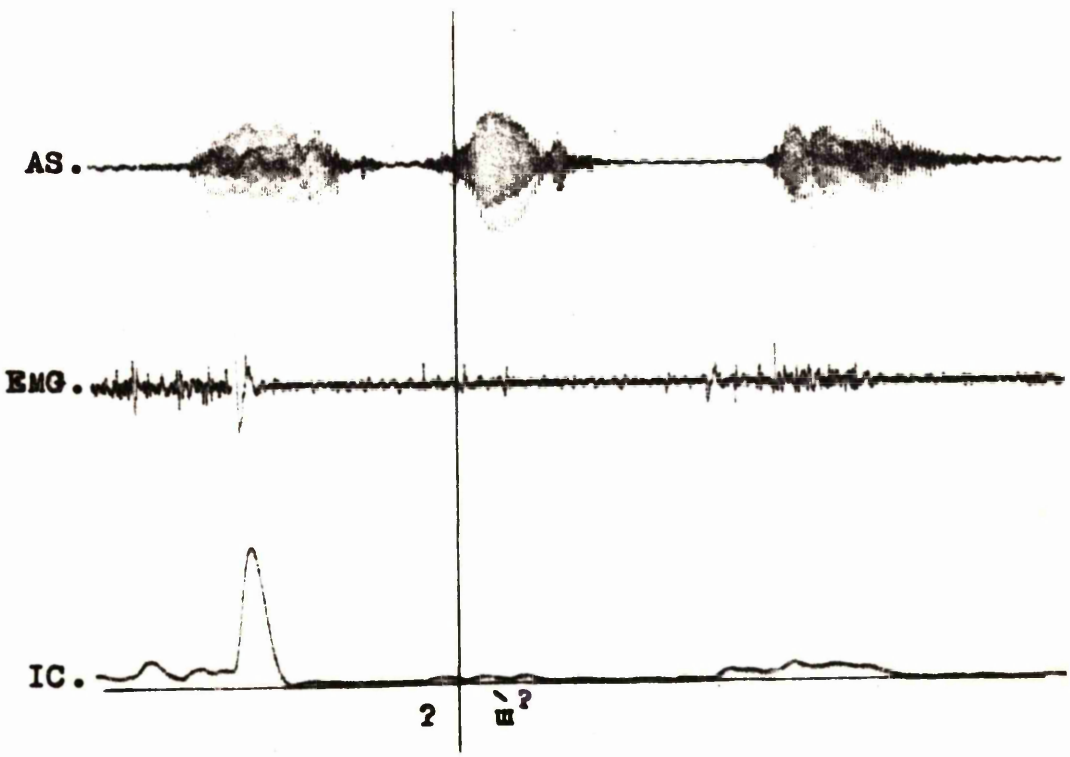

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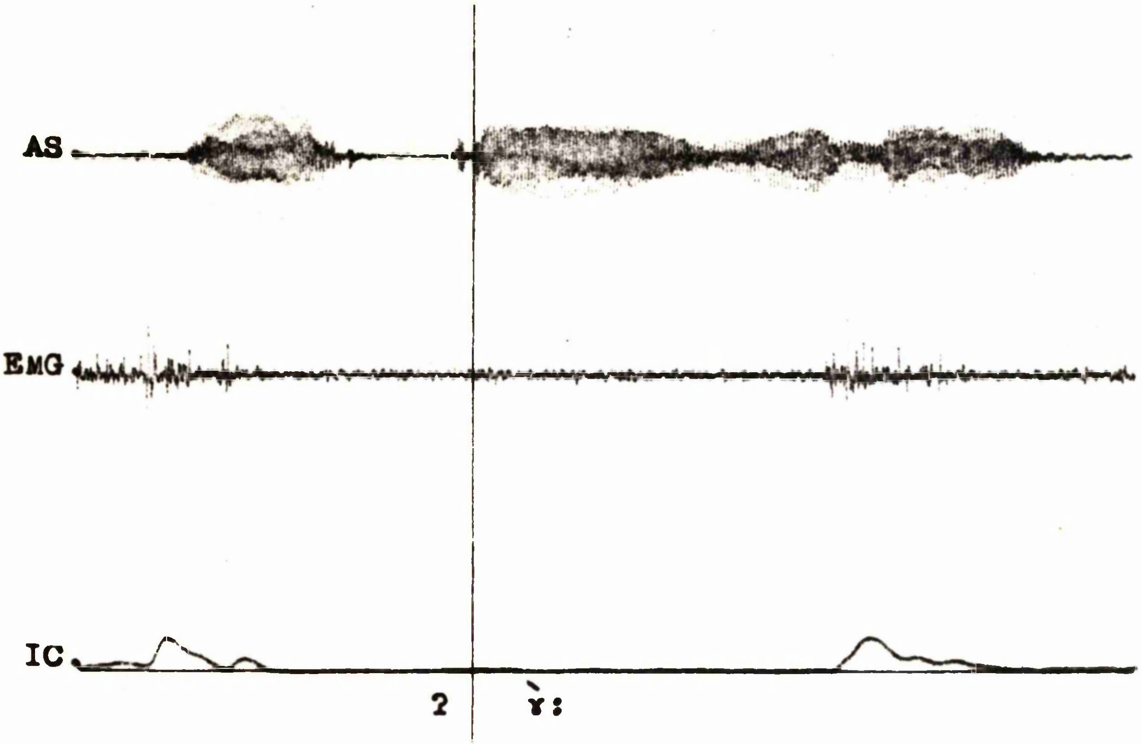
EMG XXX



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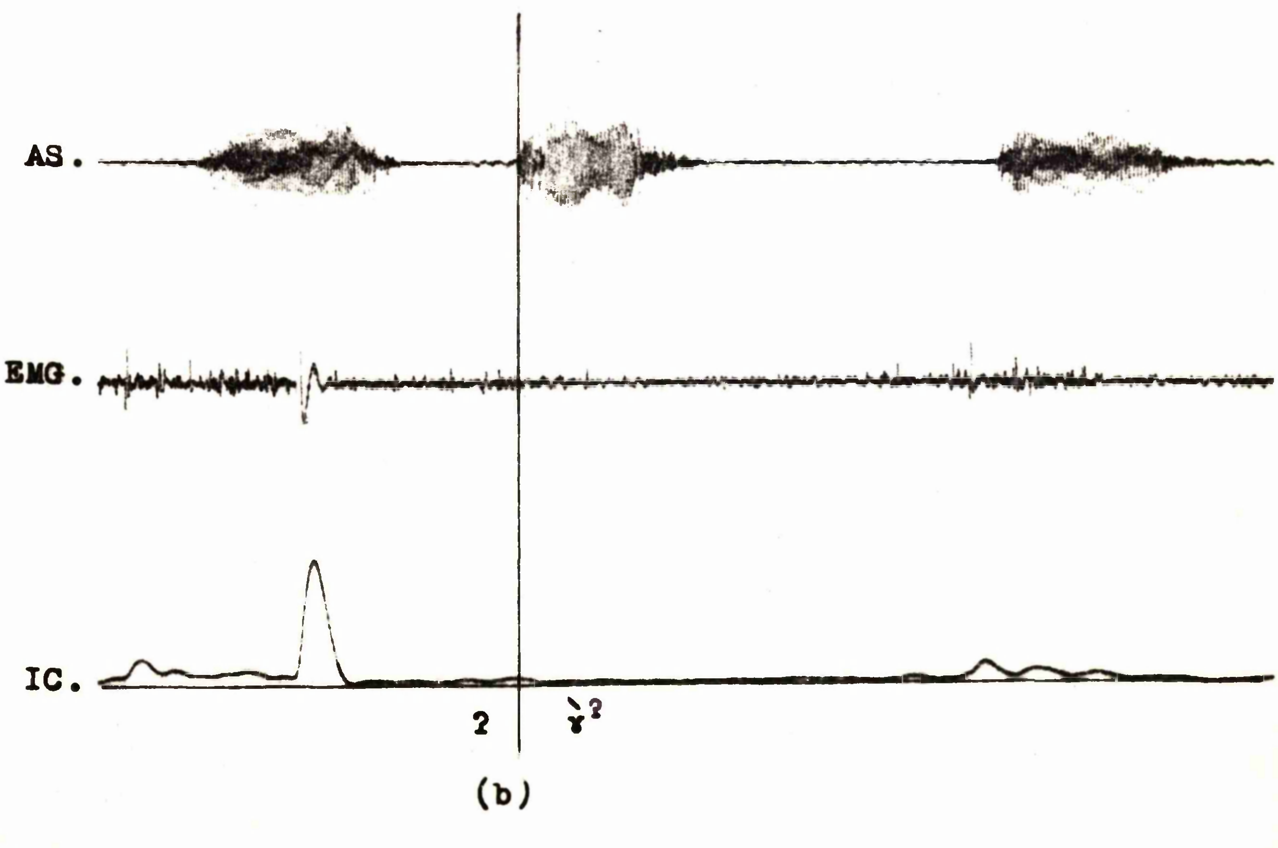
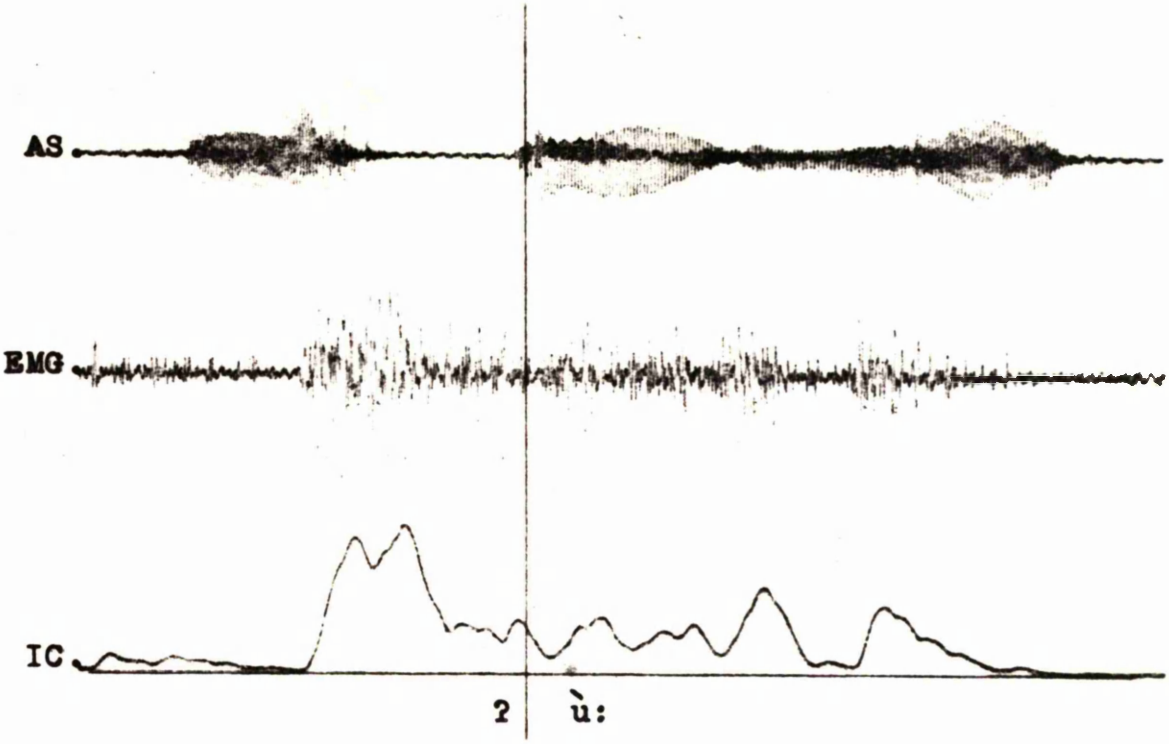


(b)

EMG XXXI



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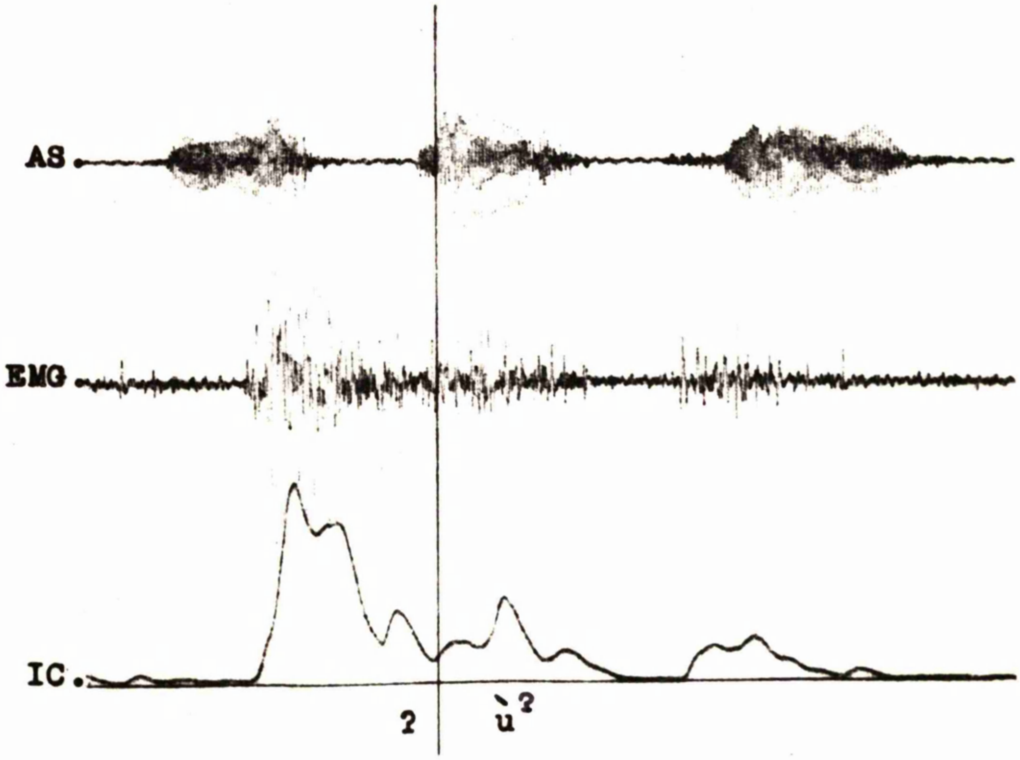
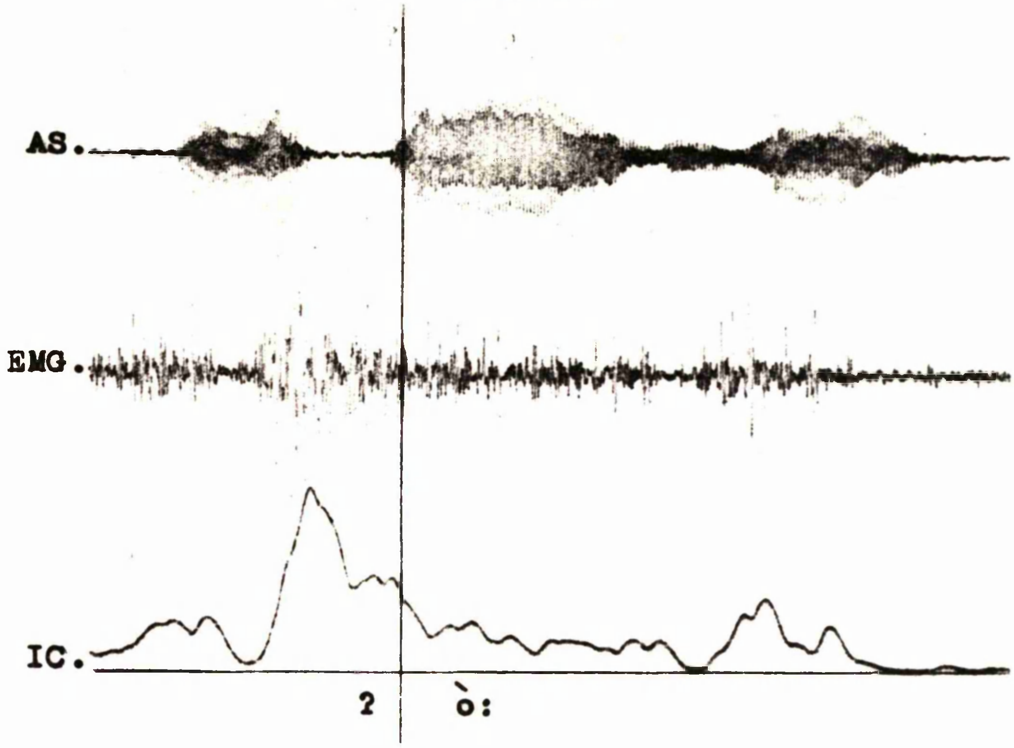


(b)

EMG XXXII



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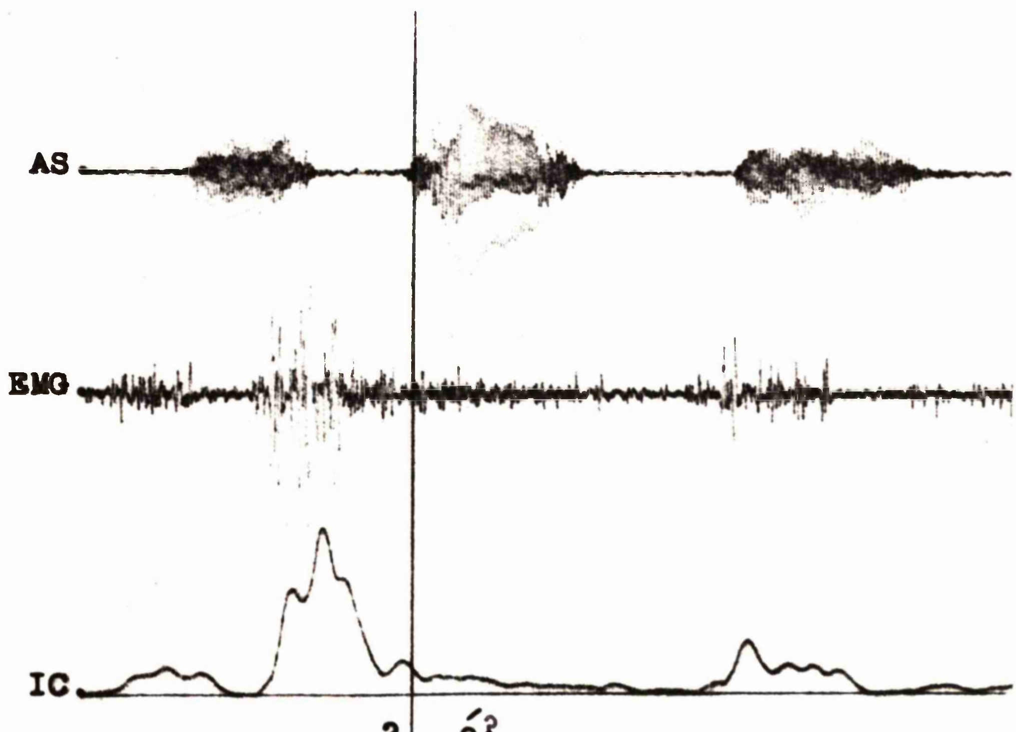

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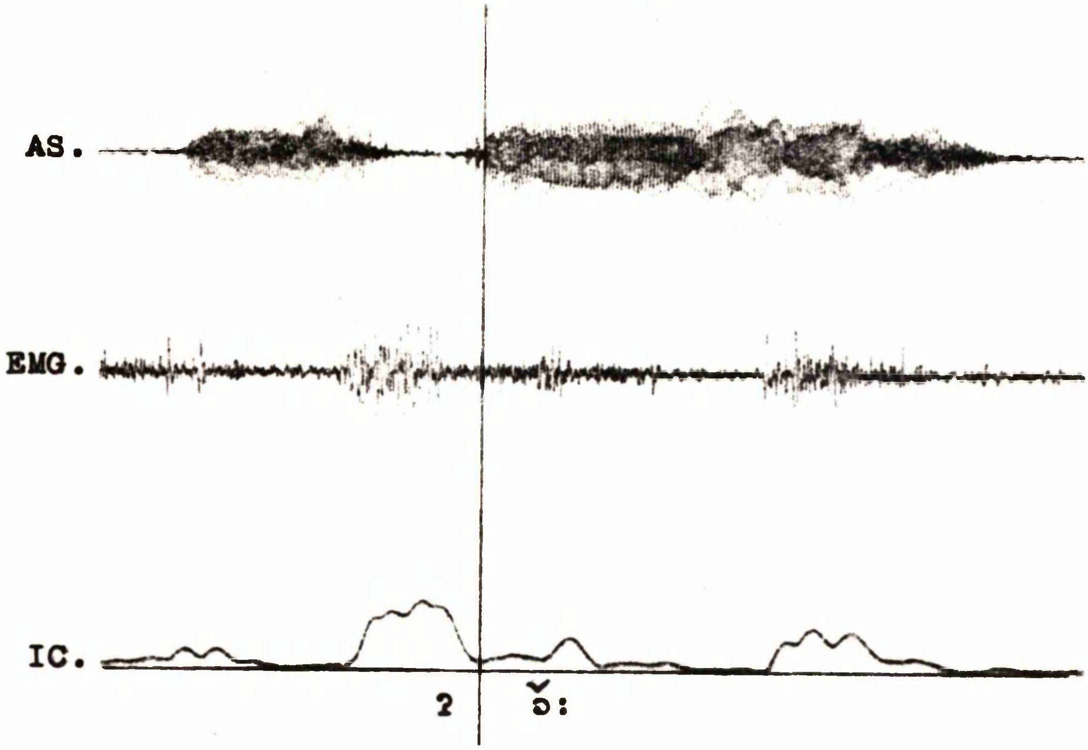
EMG XXXIII



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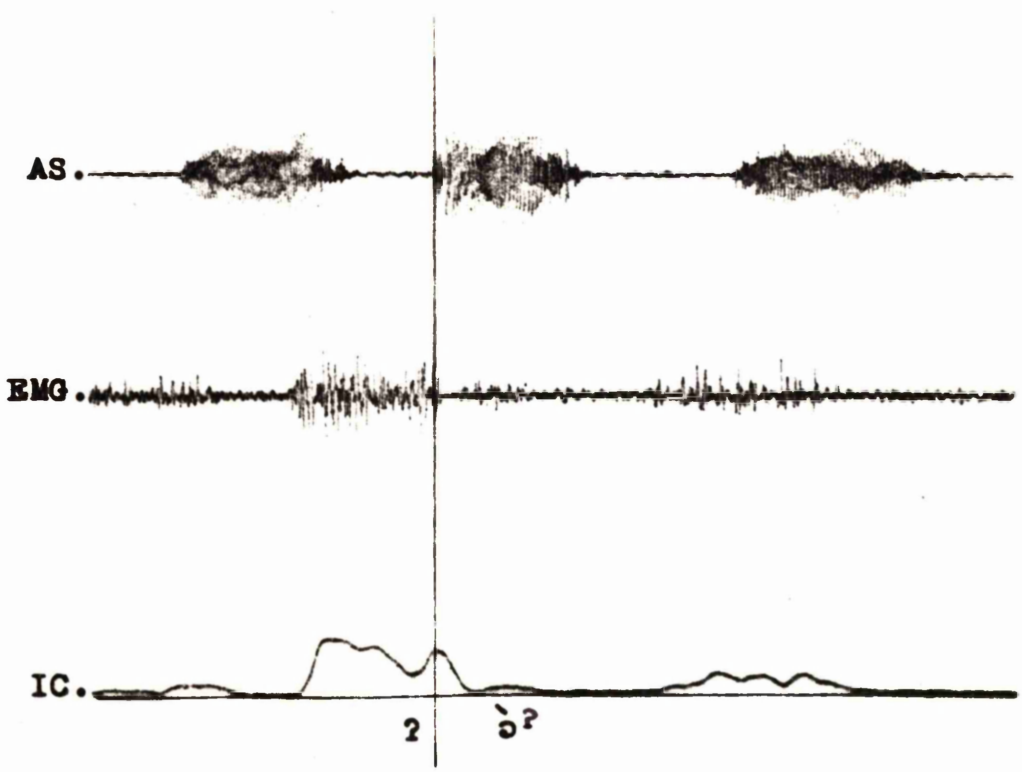

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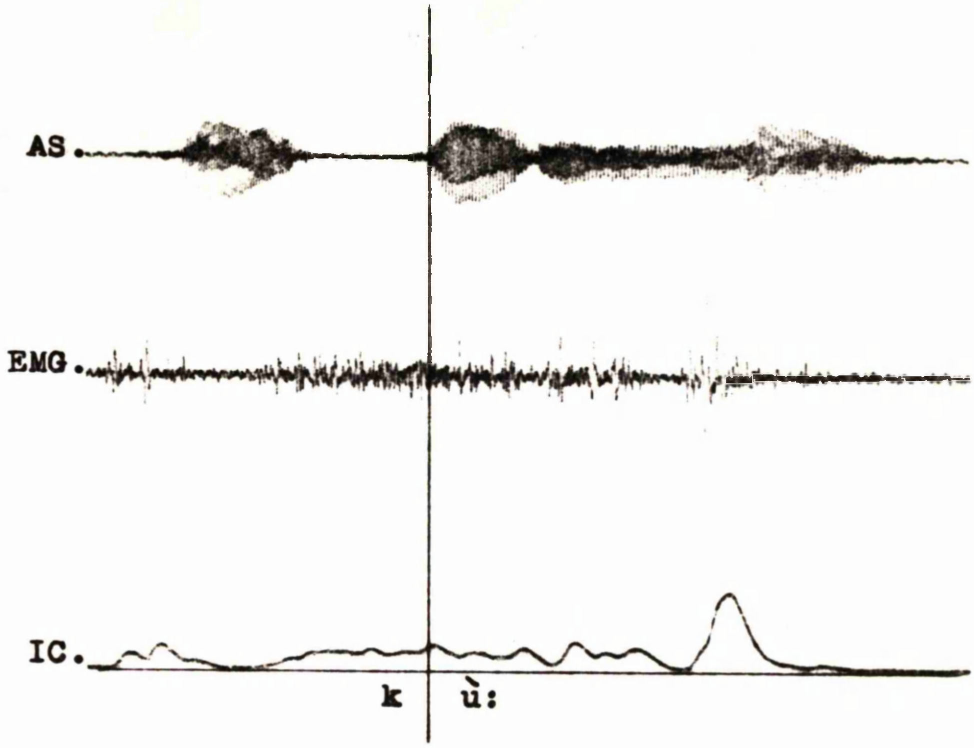
EMG XXXIV



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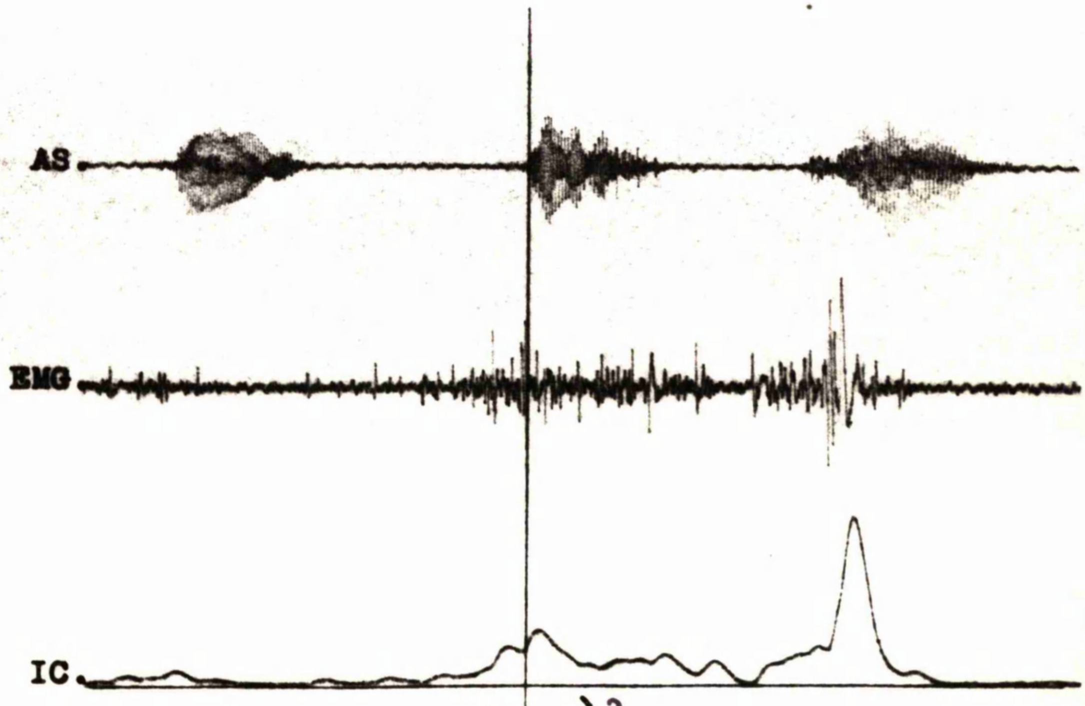

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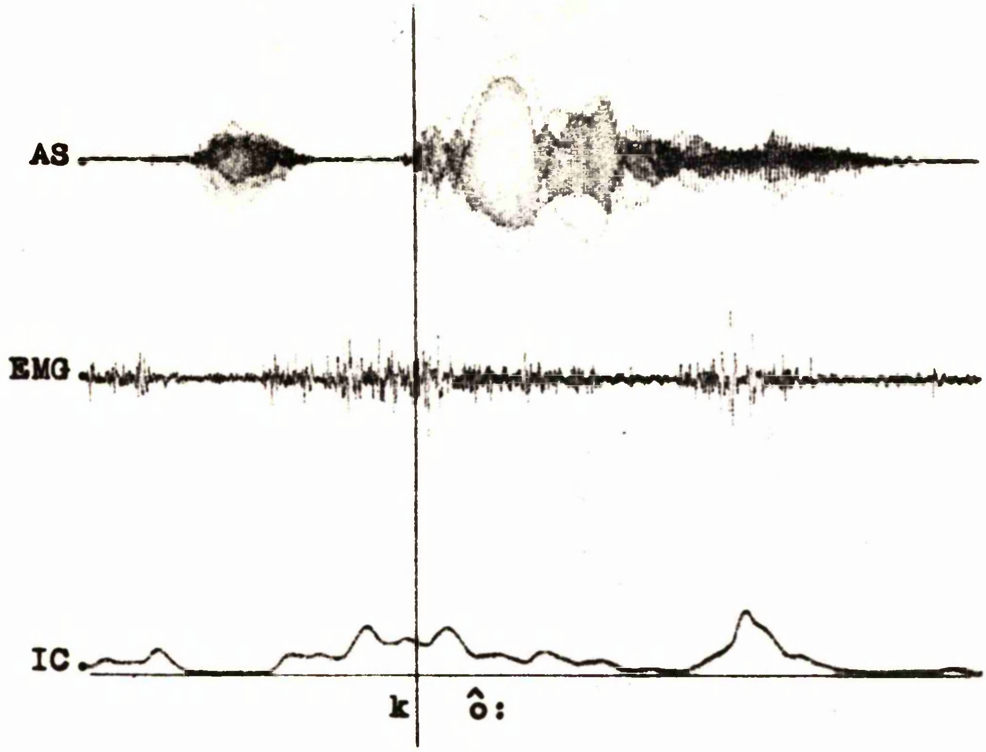
EMG XXXV



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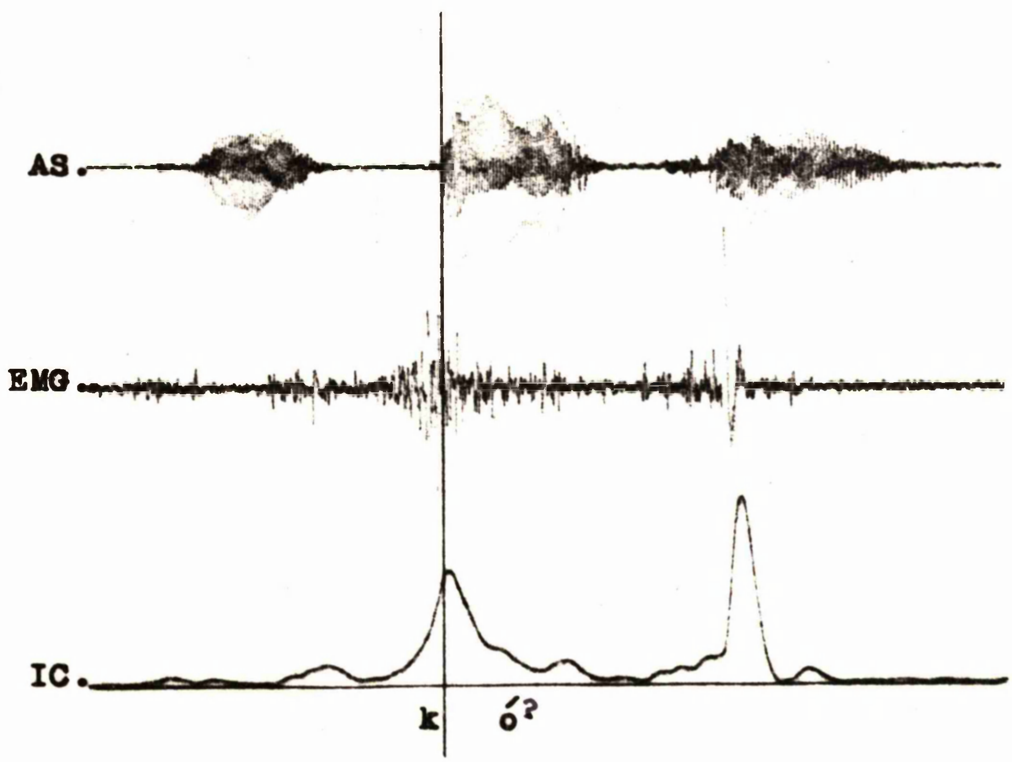

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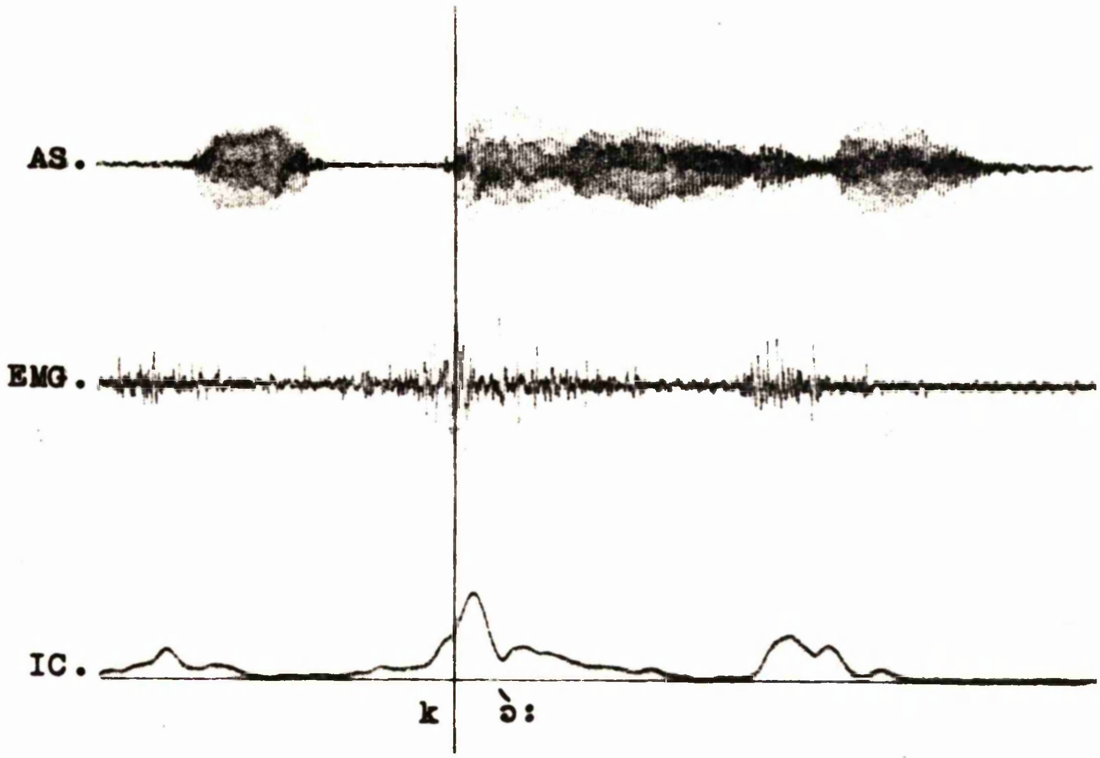
EMG XXXVI



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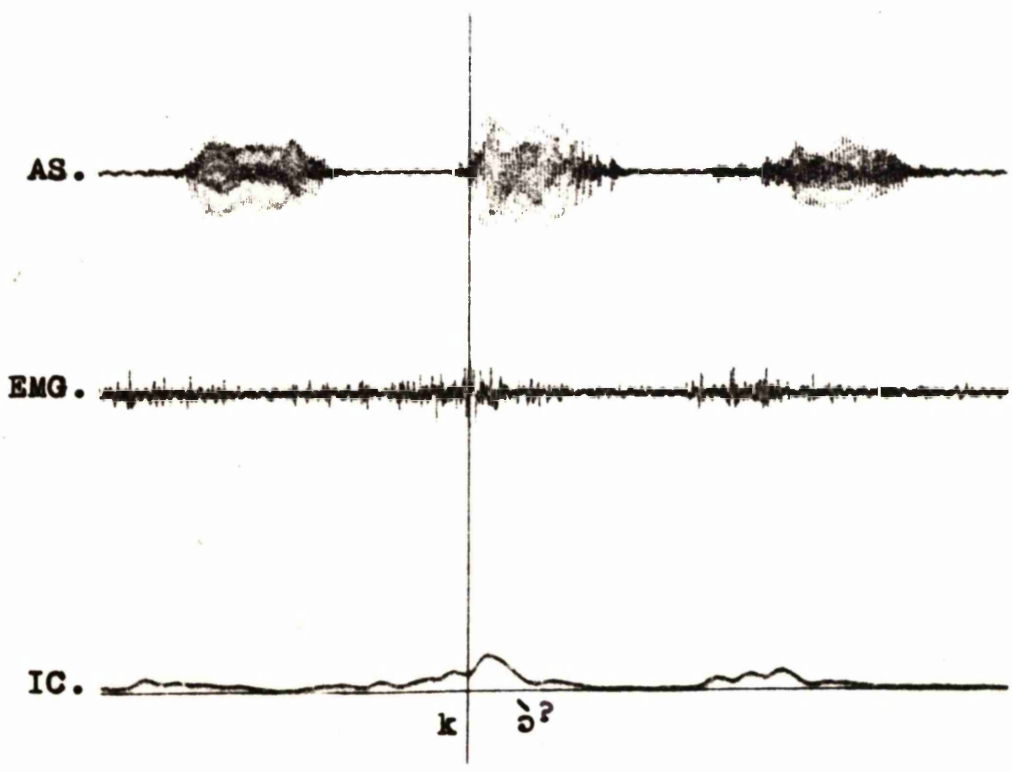

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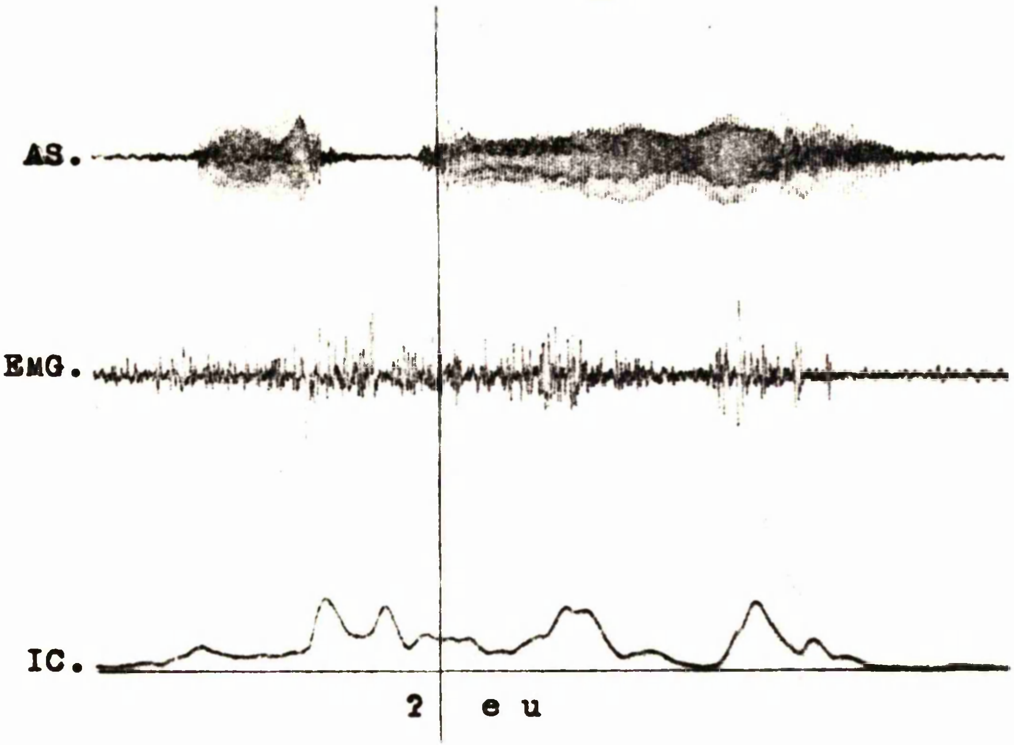
EMG XXXVII



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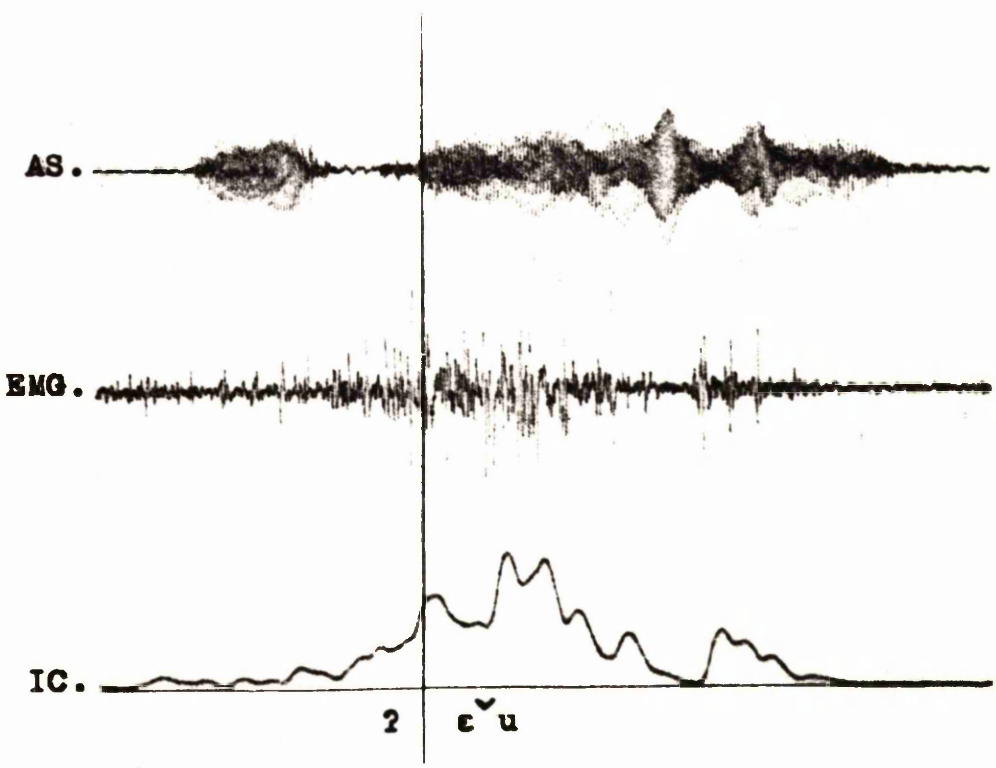

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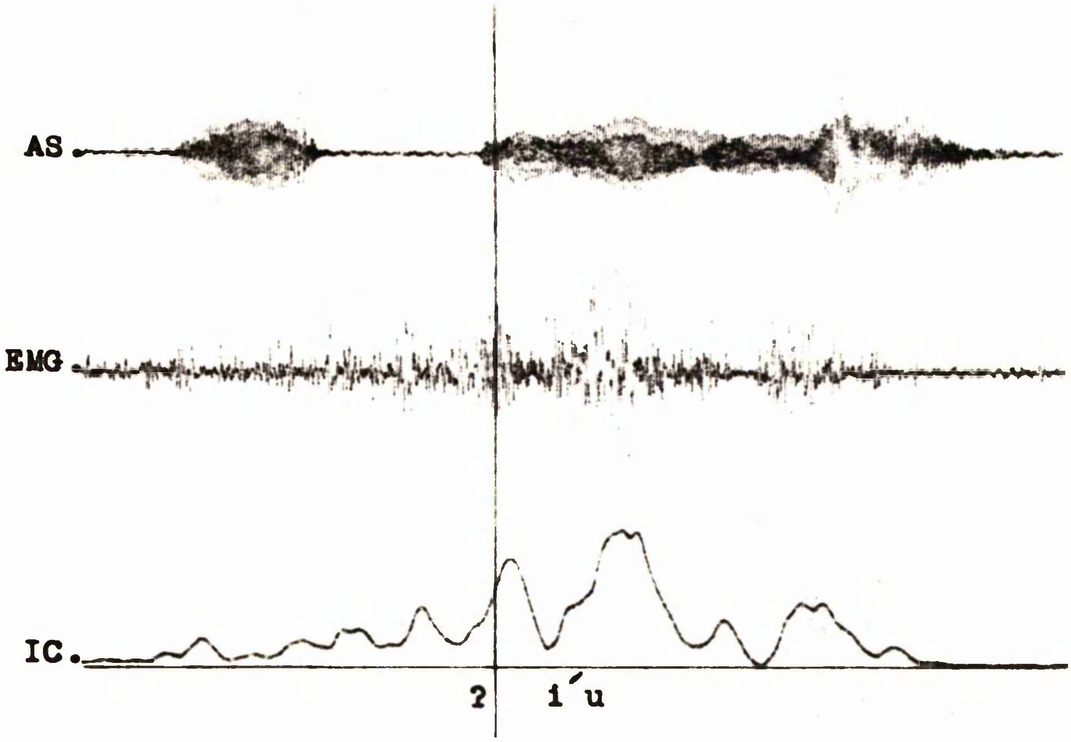
EMG XXXVIII



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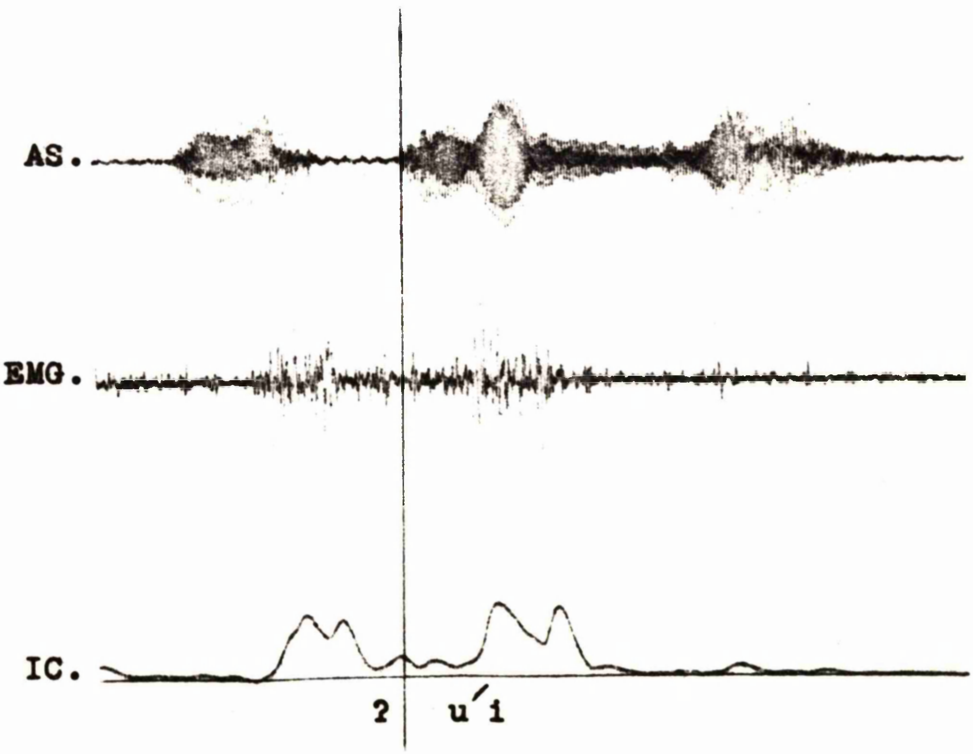

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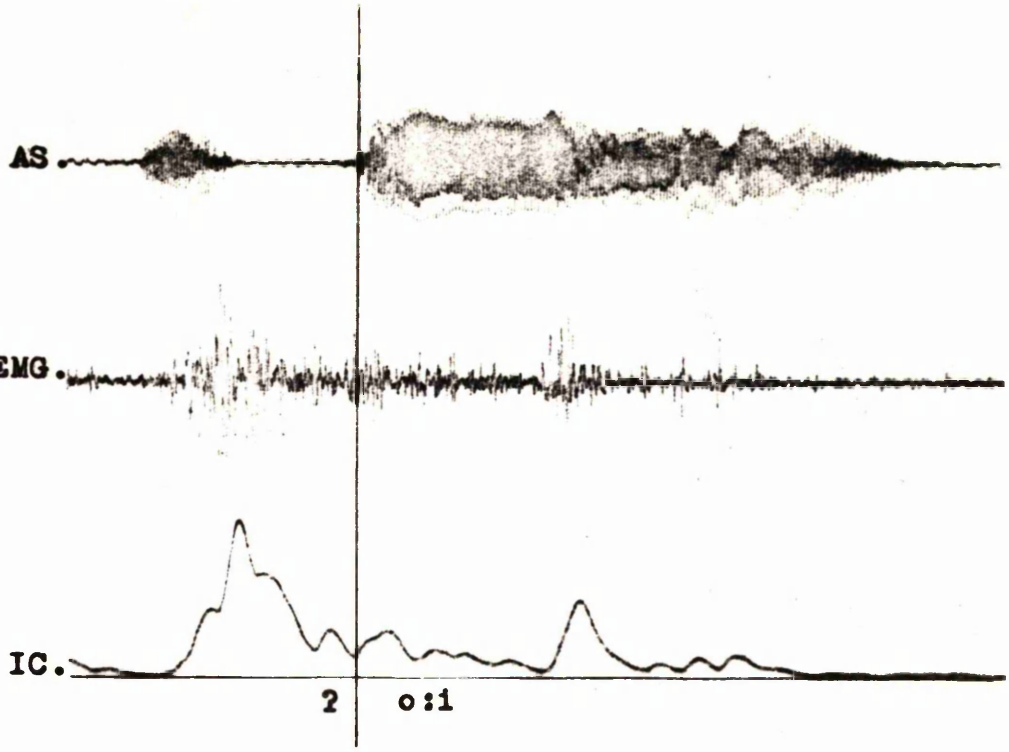
EMG XXXIX



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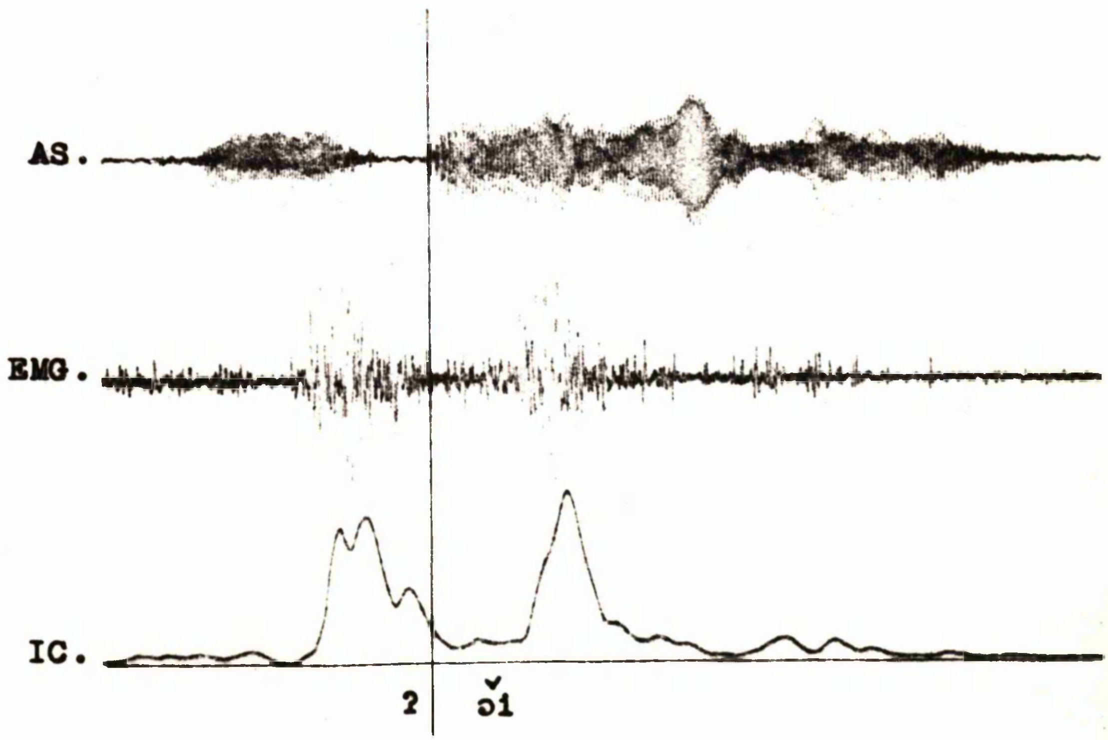

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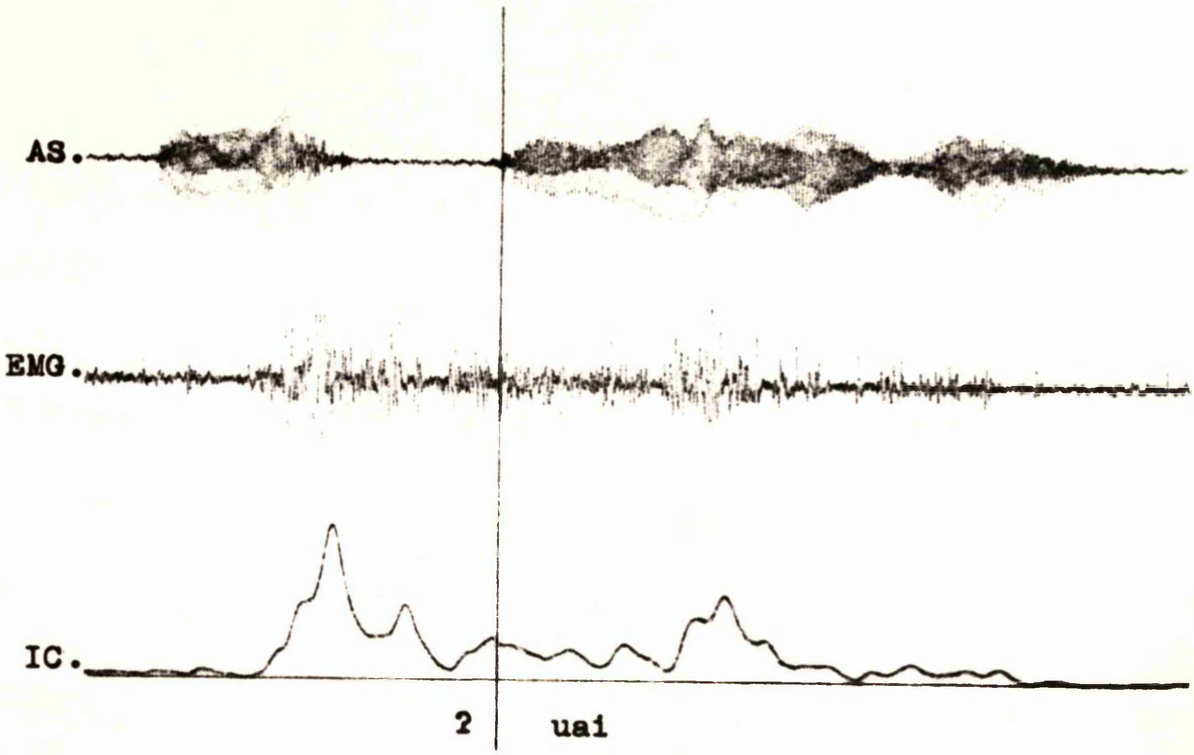
EMG XL



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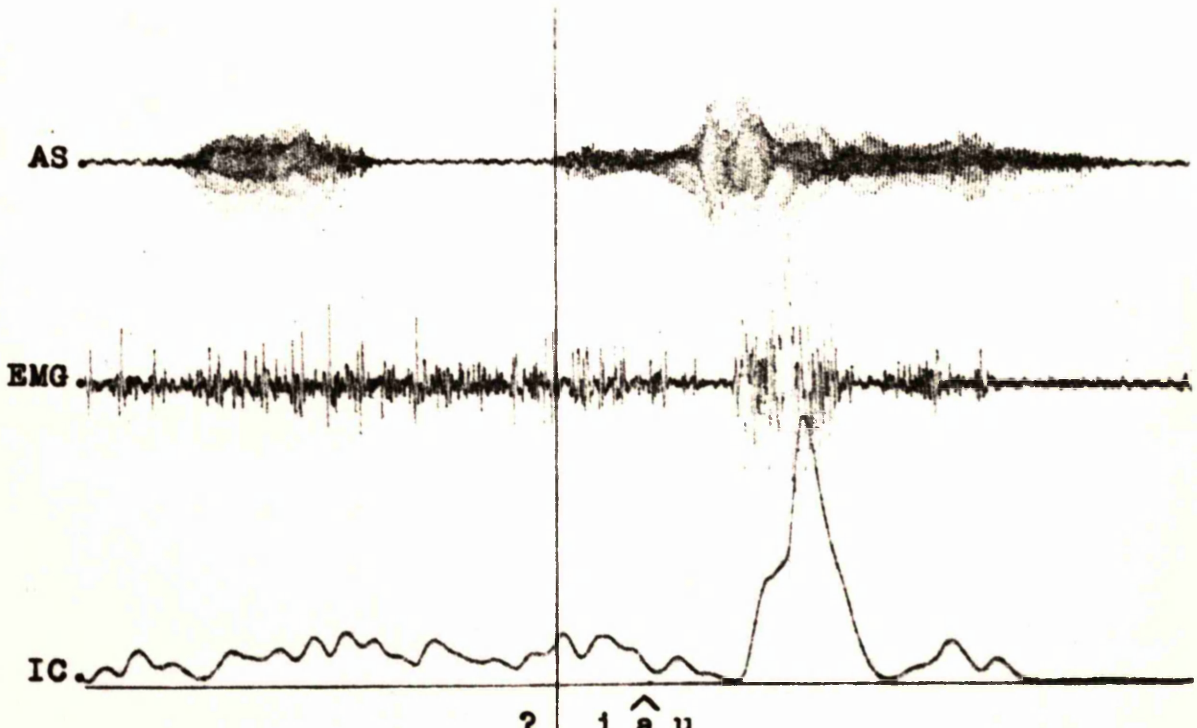


(b)

CHAPTER 8

MUSCULAR COORDINATION

In giving muscular activity descriptions of speech, it would be, in fact, more appropriate to consider muscle system as a whole. Excluding the motor command level, speech is the result of a set of muscles working simultaneously over a period of time. As Hocket (1960: 39) mentioned "Speaking is a temporal process, a succession of articulatory events in time, and any static survey of the speech tract misses many significant contrasts which appear only by virtue of the arrangement of events in time."

At the present, electromyographic investigation provides the available technique by which the dynamic coordinations of muscles for speech function can be observed. Consequently, the present study of muscular coordination has been concentrated on the timing dimension of the muscular integrated curves. To be able to study the muscular activity along the time axis, the onset of the acoustic signal was employed as the line-up point.

It must be stated, as a matter of fact, that the force of contraction of each muscle is an unreliable basis for a comparative study. The actual relationship between the electromyographic potentials and the force of contraction still needs more investigation, since the phenomena involved in the contraction of muscle are still imperfectly understood. For example, a small increase of electrical activity in one muscle may represent a large part of its capacity for contraction, whereas in another muscle it may represent only a small portion. Although, the large motor unit tends to produce the large potential there is, nevertheless, a factor connected with the distance of the motor units from the electrodes, (Basmajian 1974: 15). In other words, valid comparisons among muscles still require rather precise knowledge of the relationship between the level of activity and muscular action potentials or electromyographic potentials of each muscle.

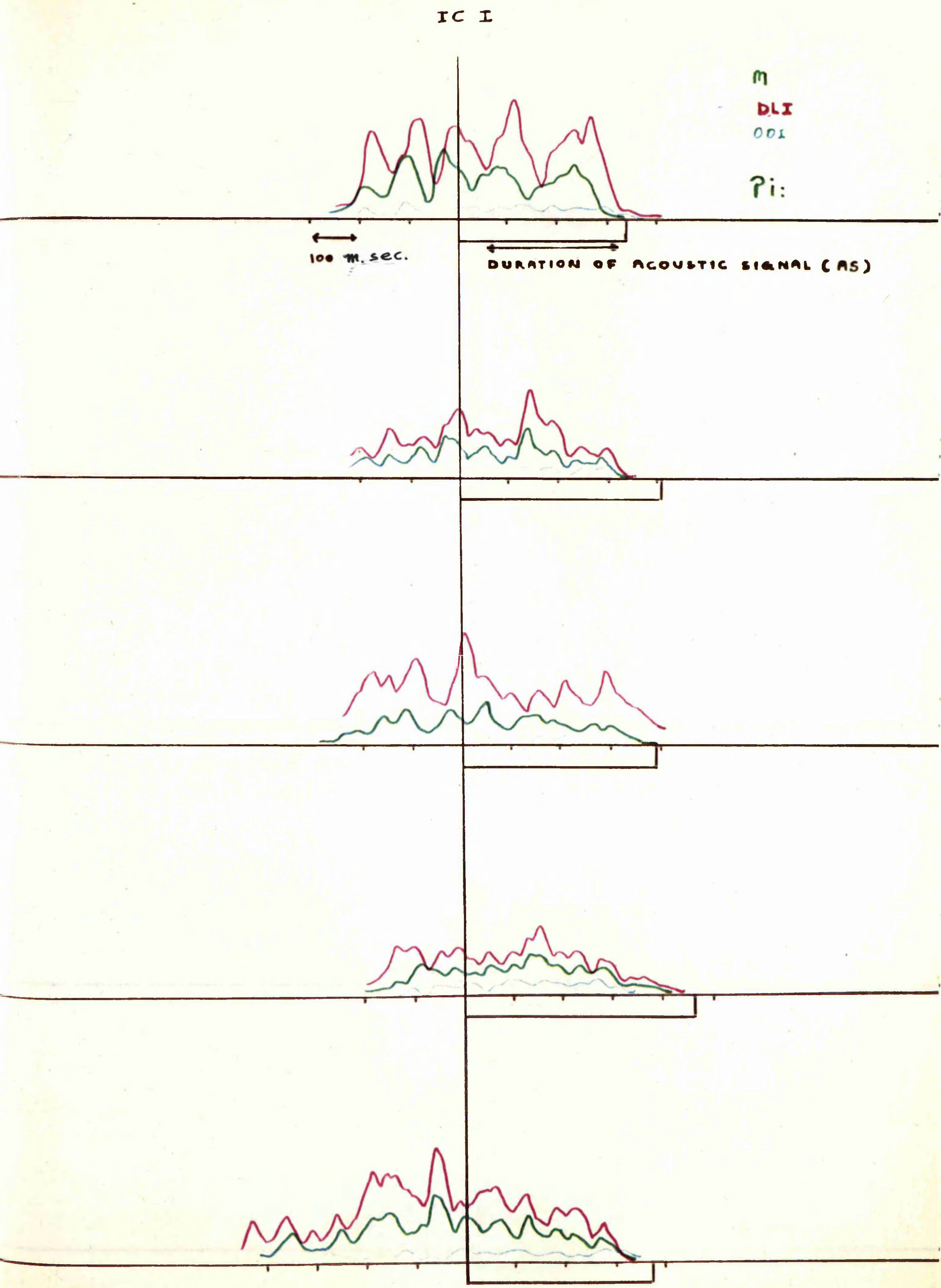
Coordination in monophthongs.

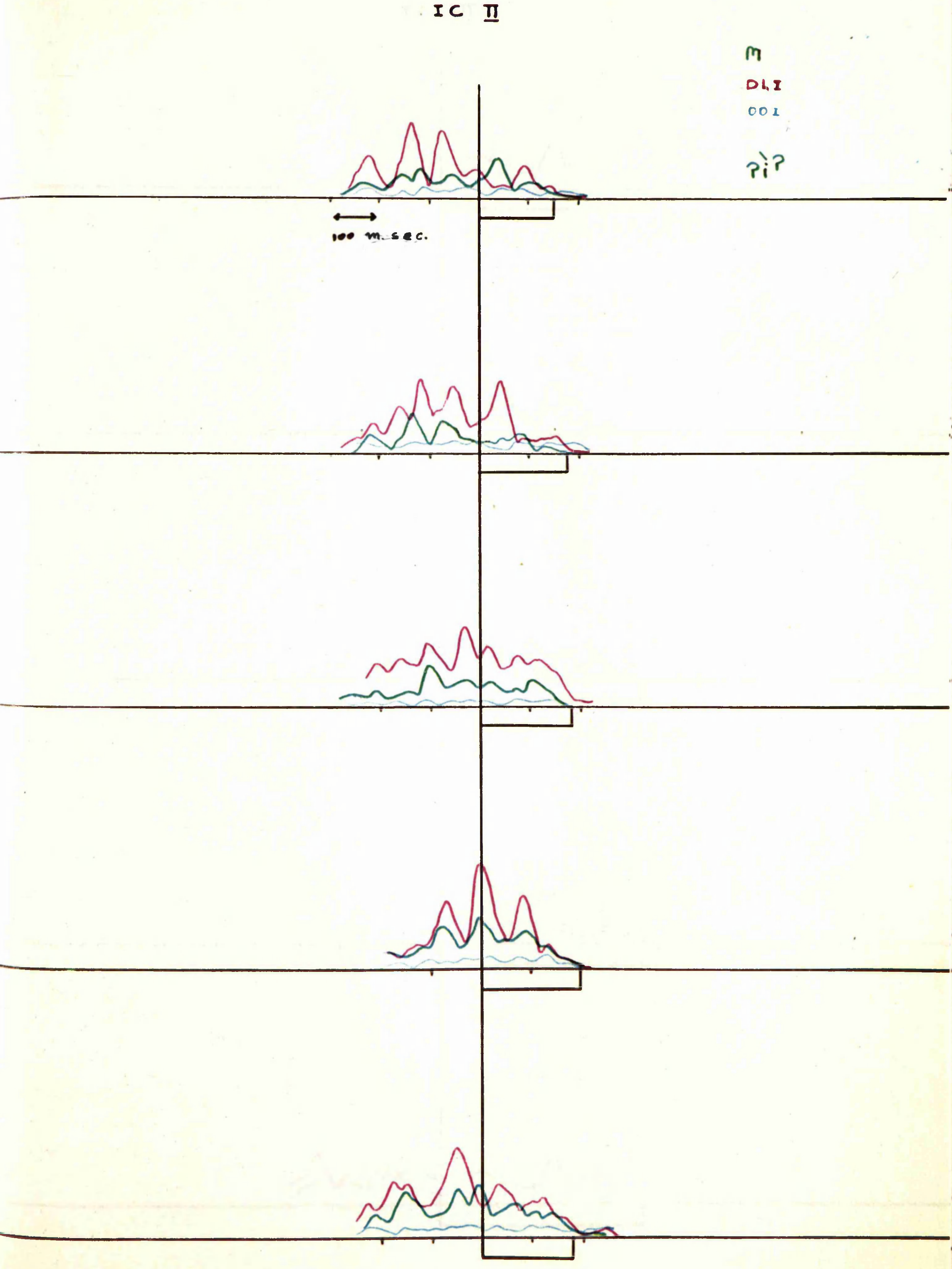
Front unrounded vowels. The data are of the five utterances of front unrounded [iː, i, eː, e, ɛː, ɛ] preceded by [ʔ] and [k]. In the following presentation each integrated curve (IC) is the representation of each muscle activating for each utterance. M, DLI, and OOI stand for mentalis, depressor labii inferioris and orbicualris oris inferioris, respectively. The presentation reveals the time dimension (in msec.) of muscular coordinations among the three muscles (see IC I-XII).

Comments on IC I-XII.

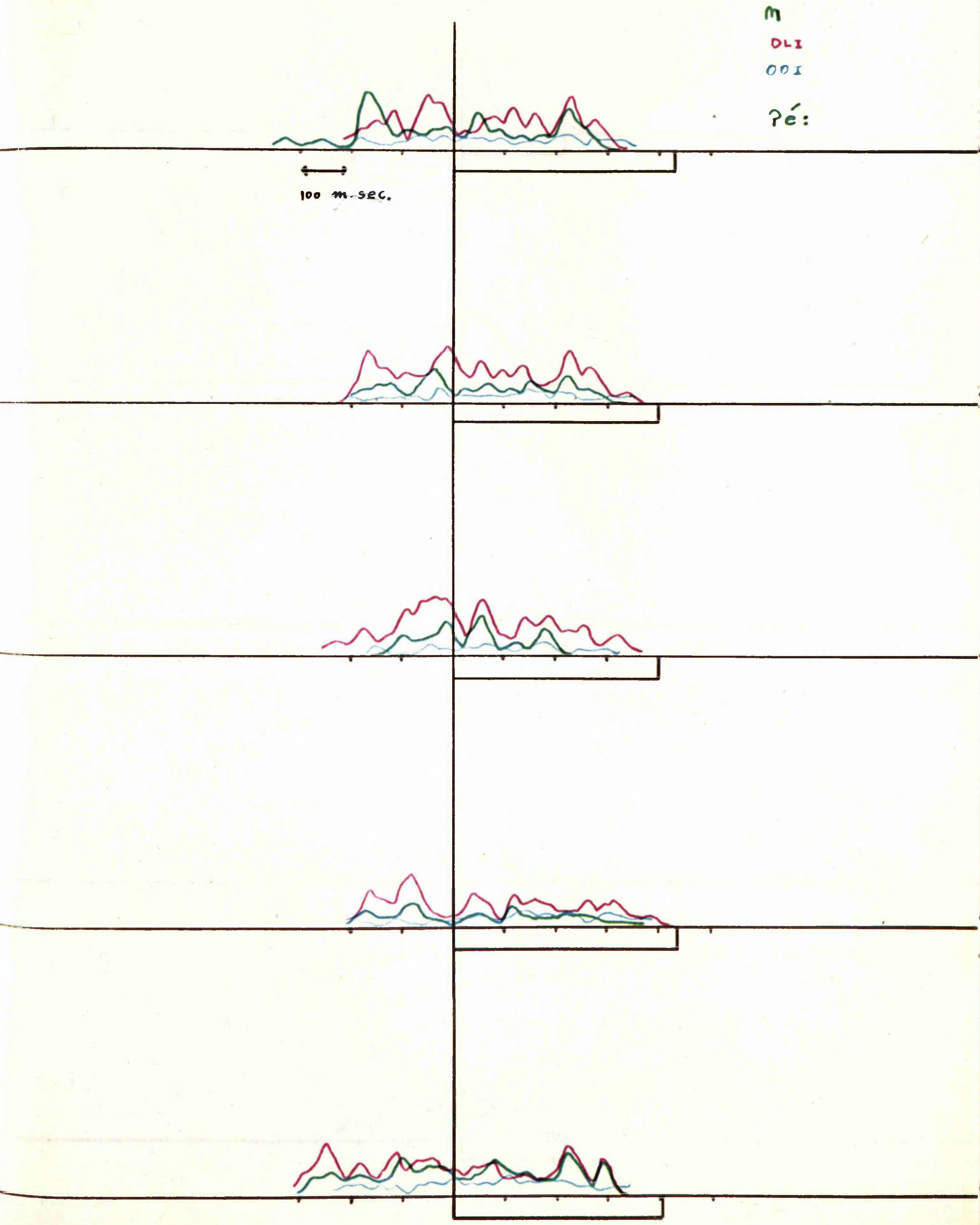
In terms of timing, the relationship between the occurrence of the high peaks and the onset of the acoustic signal, except in the utternaces of the [ɛ], seems to have a consistent characteristic. That is, in the long vocalic utterances the high peaks tend to occur after the acoustic onset. On the contrary, in the short vocalic utterances the high peaks tend to appear before the onset of the acoustic signal. For the [ɛ] the occurrence

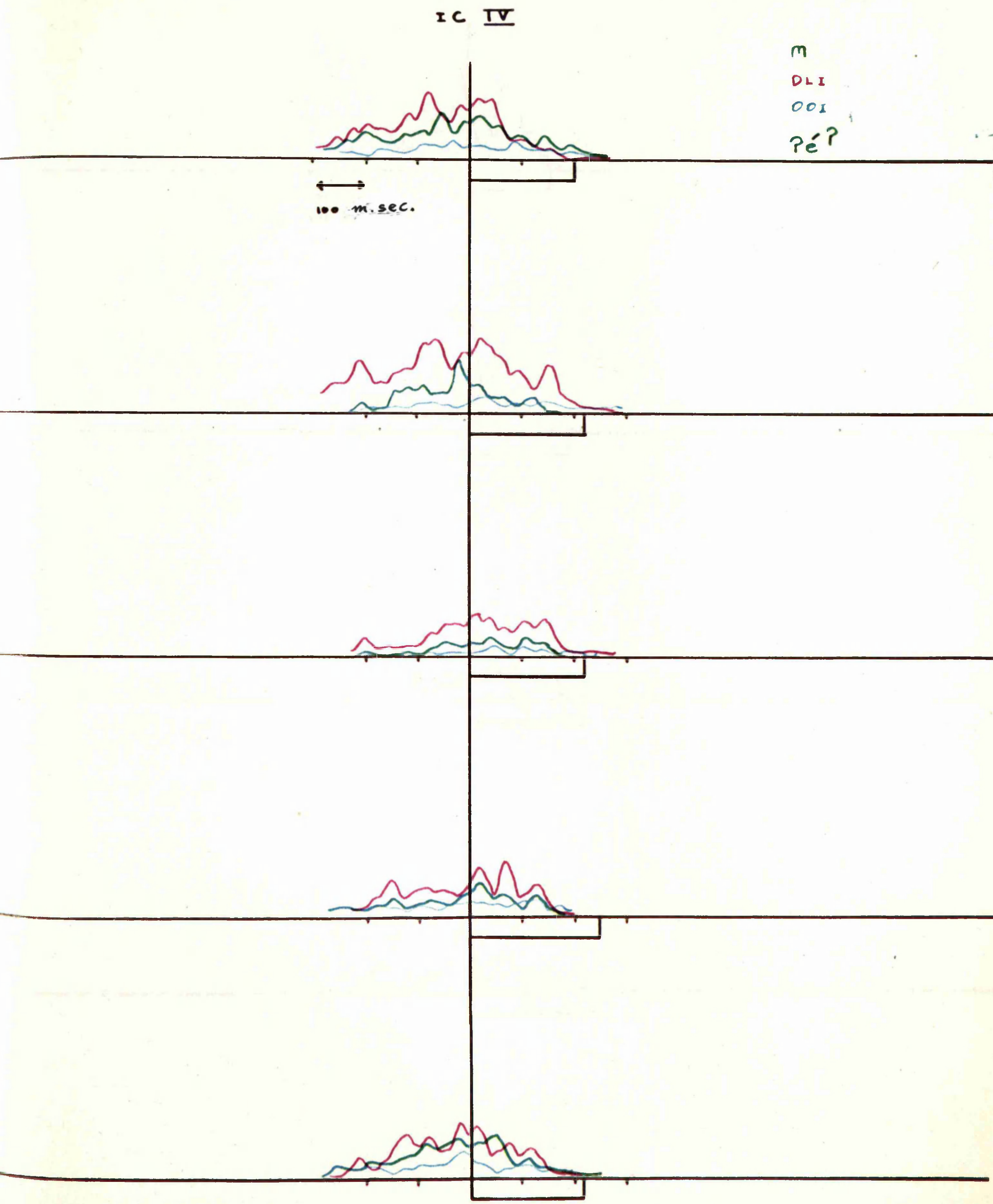
(cont./178)


IC I
m
DLI
OOI
Pi:
100 m. sec.
DURATION OF ACOUSTIC SIGNAL (AS)

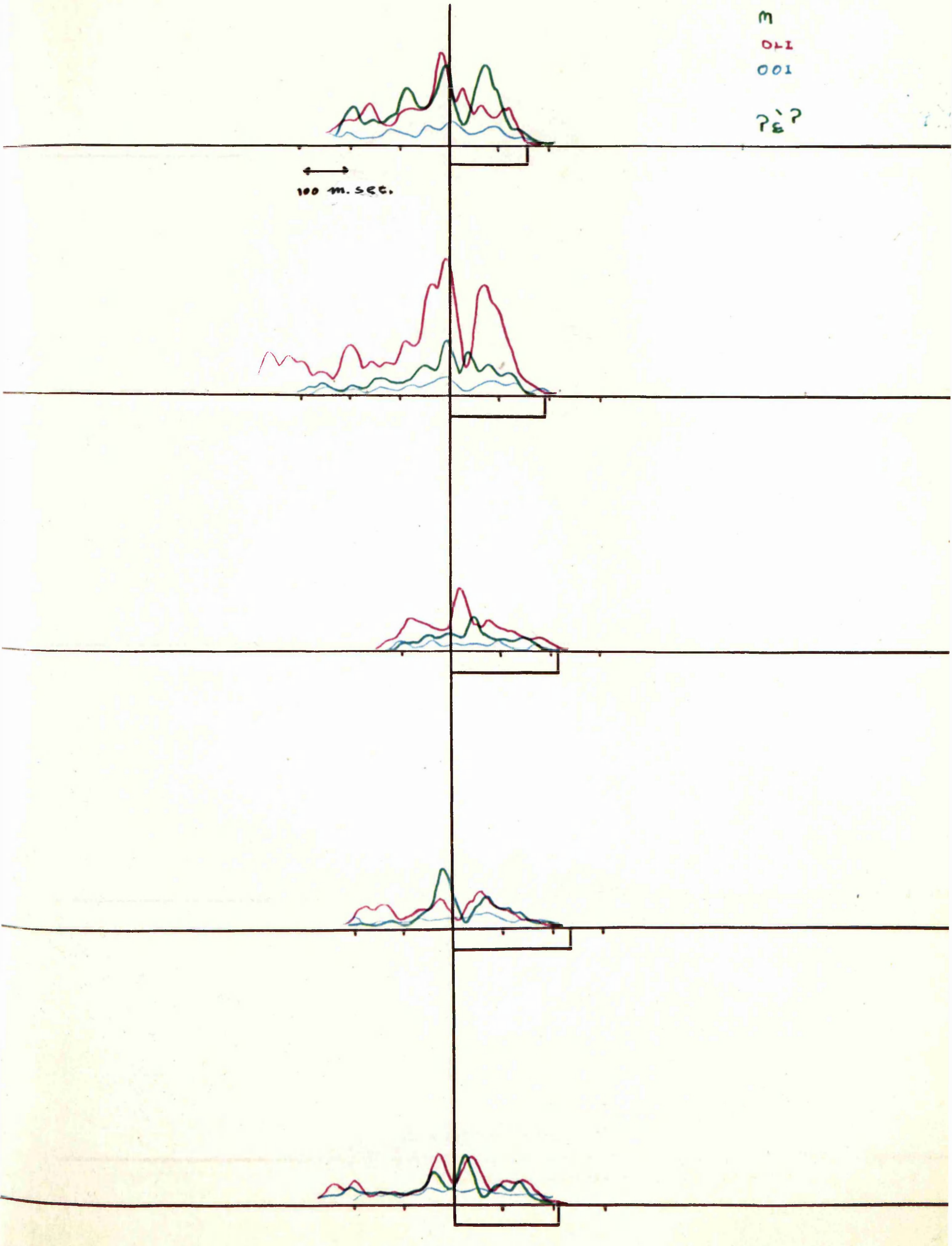

IC II
m
DI, I
OOI
?i?
100 m.sec.

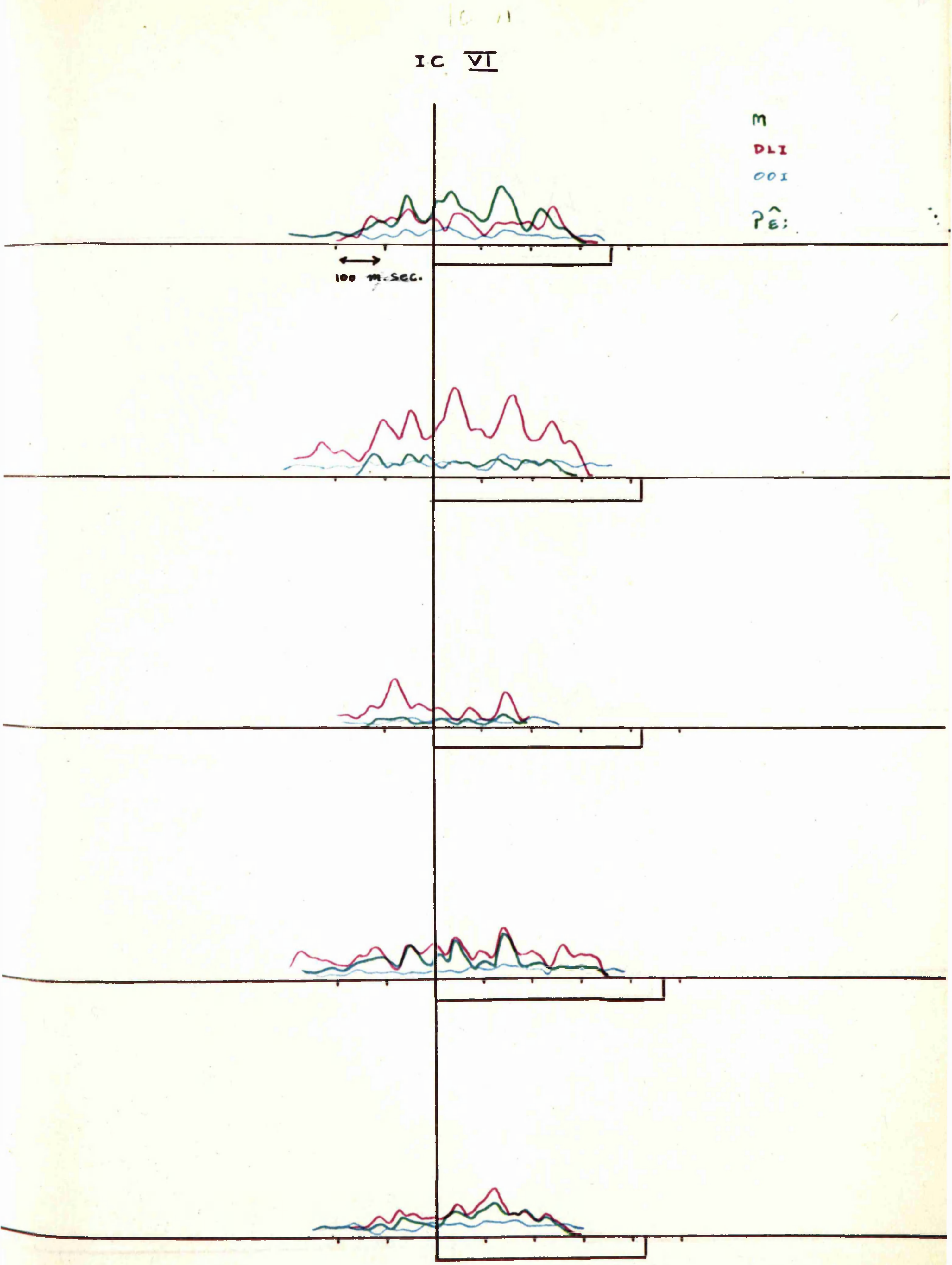
IC III



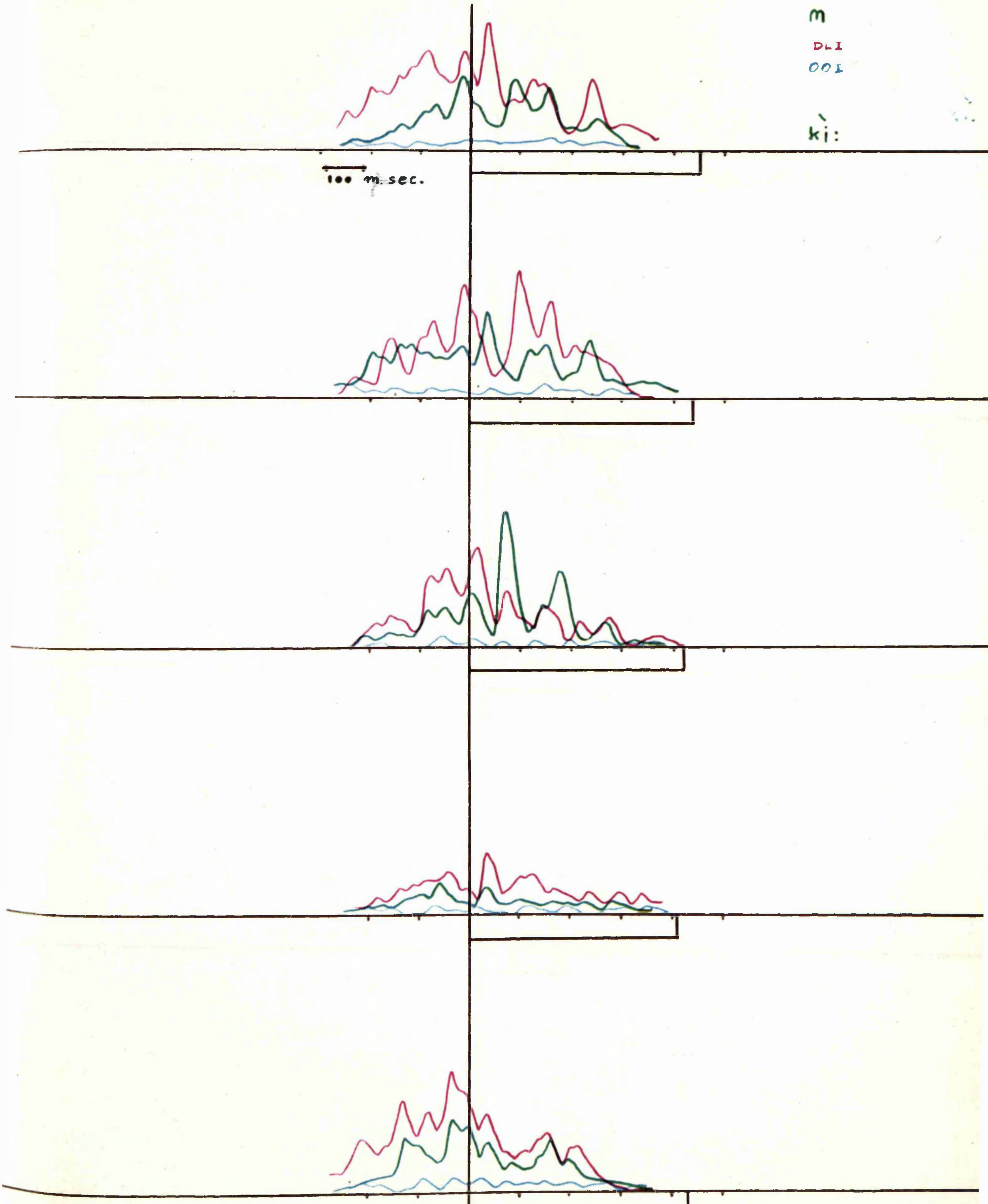

IC IV
m
DLI
OOI
?é?
100 m.sec.

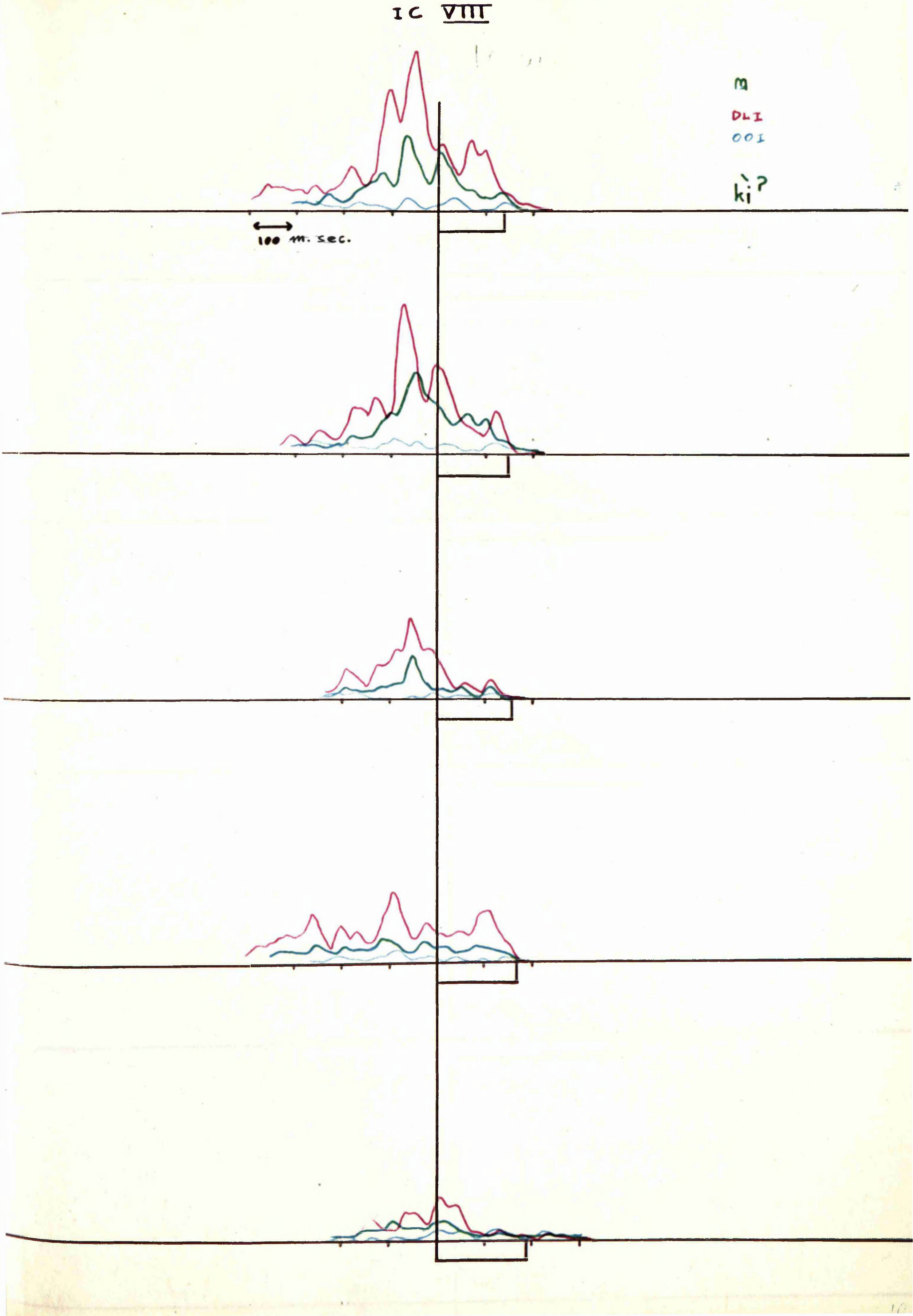
IC V



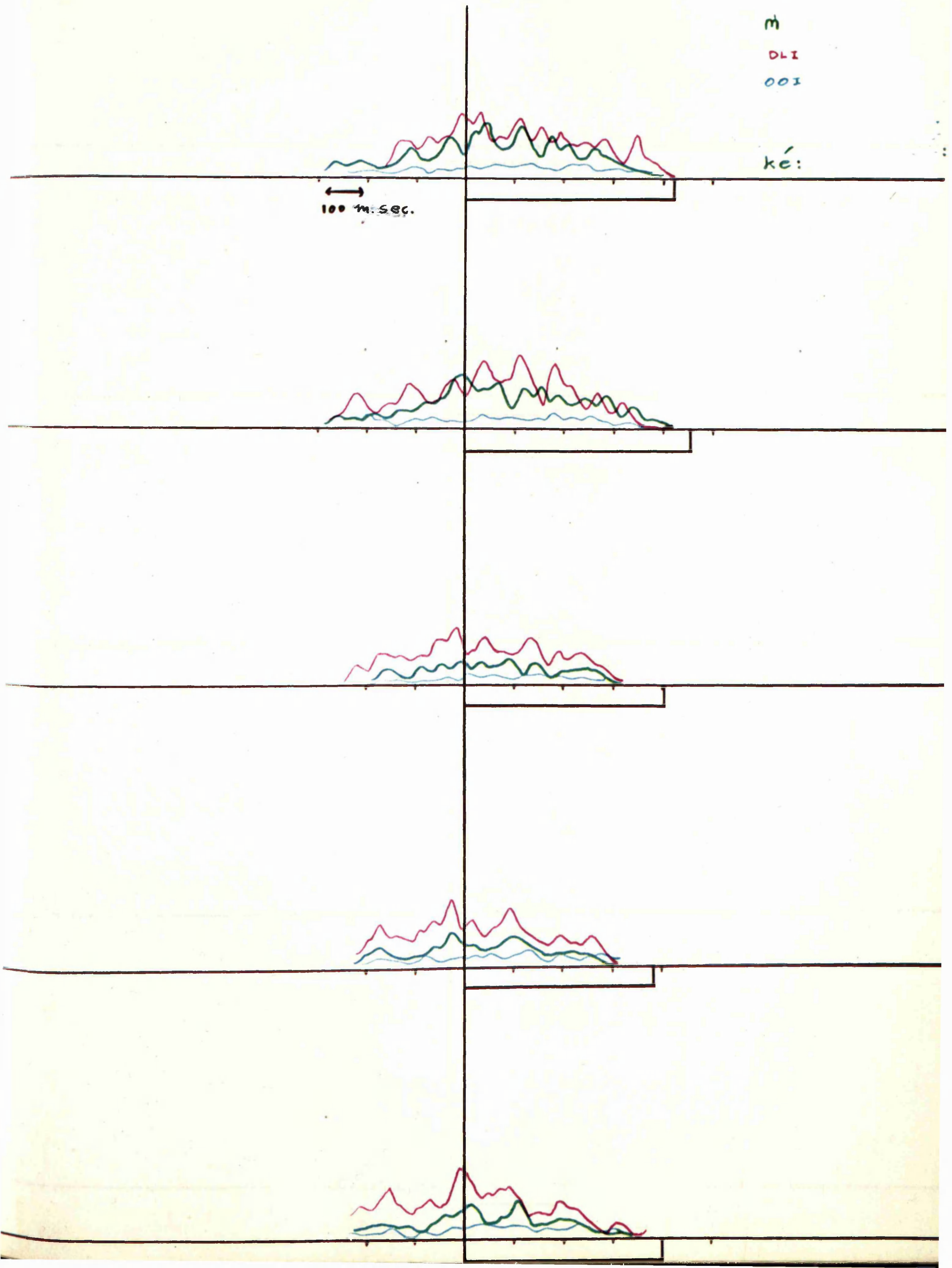

IC VI
m
DLI
OOI
ʔɛ̂:
100 m.sec.

IC VII

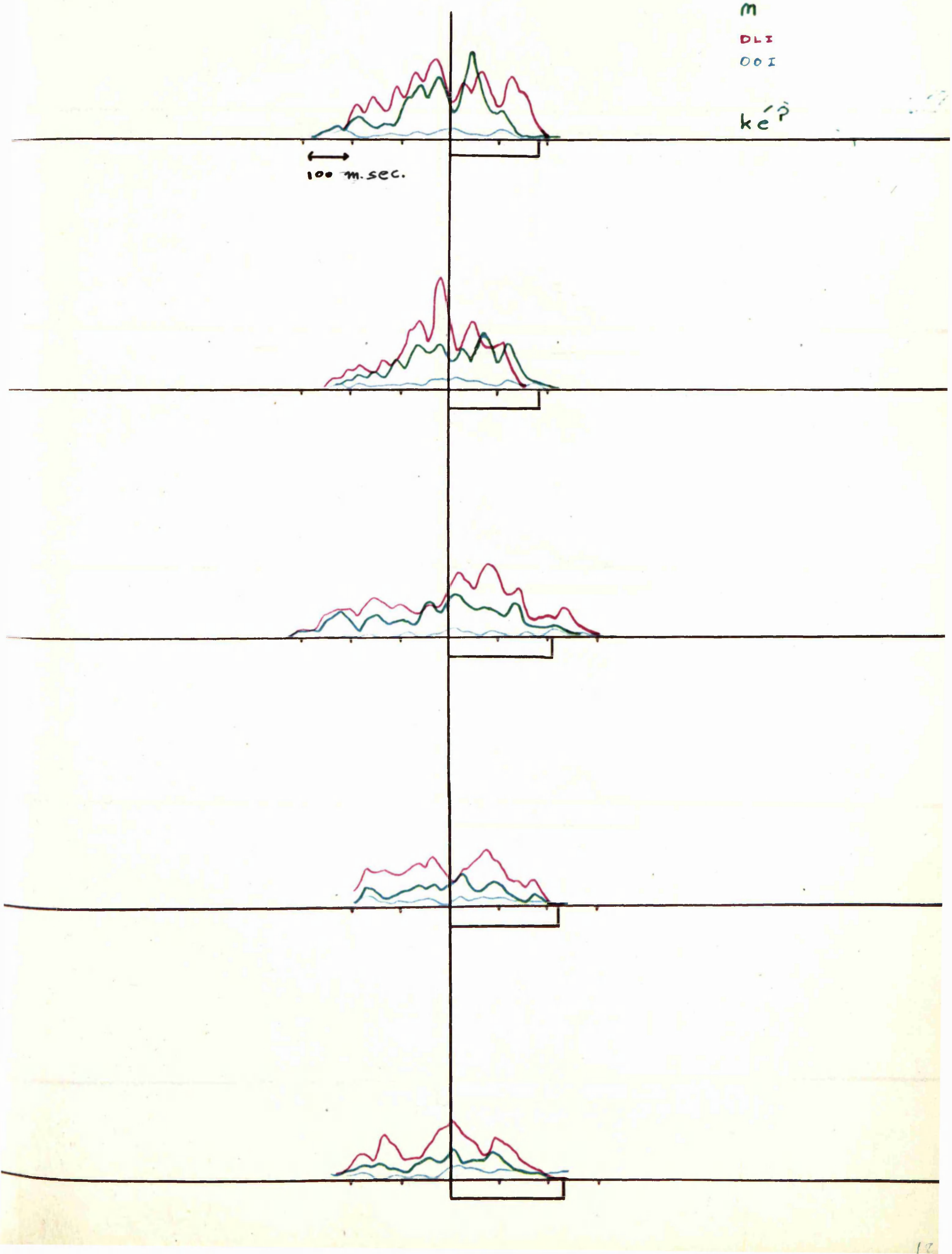



IC VIII
m
DLI
OOI
kì?
100 m. sec.

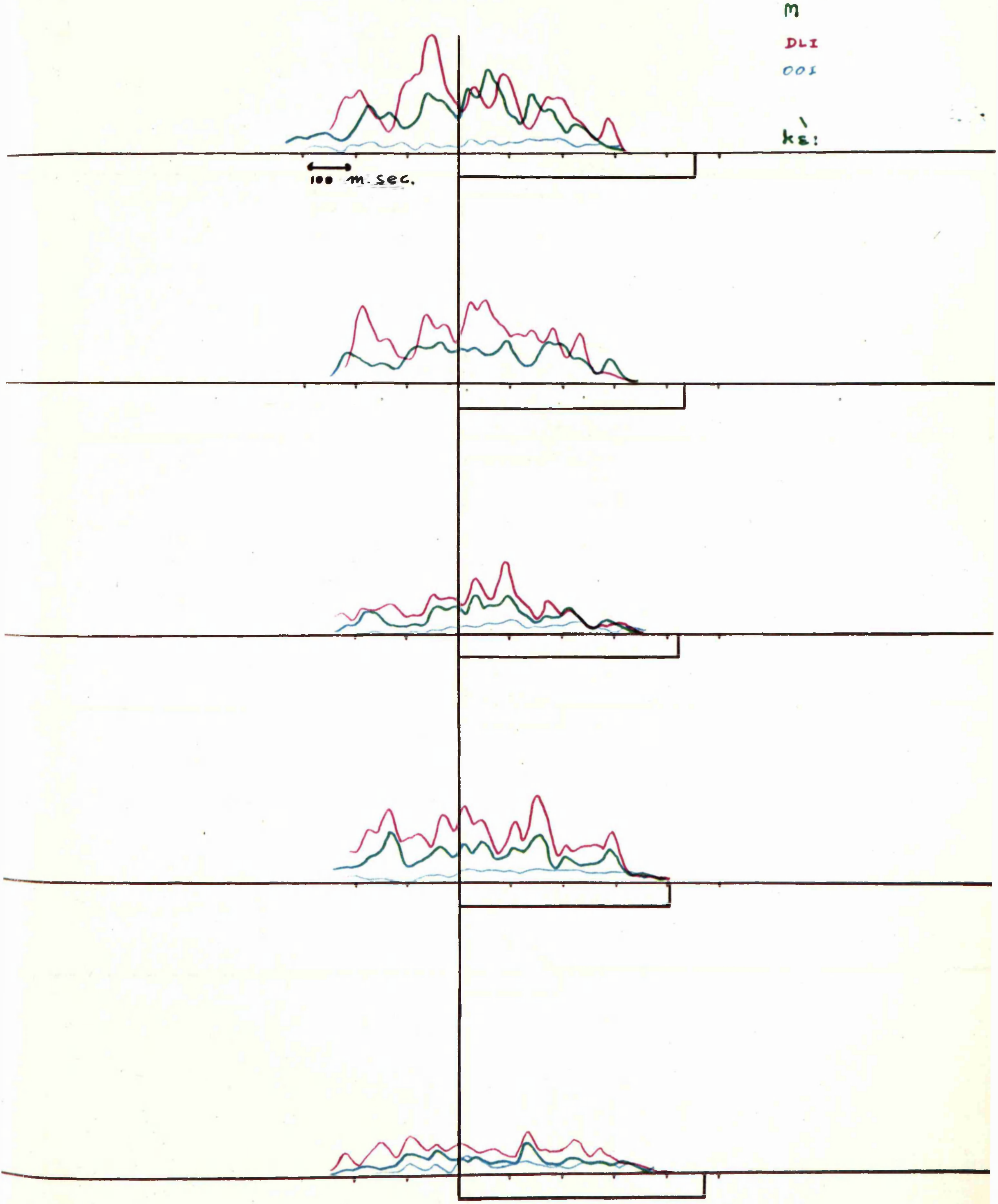
IC IX



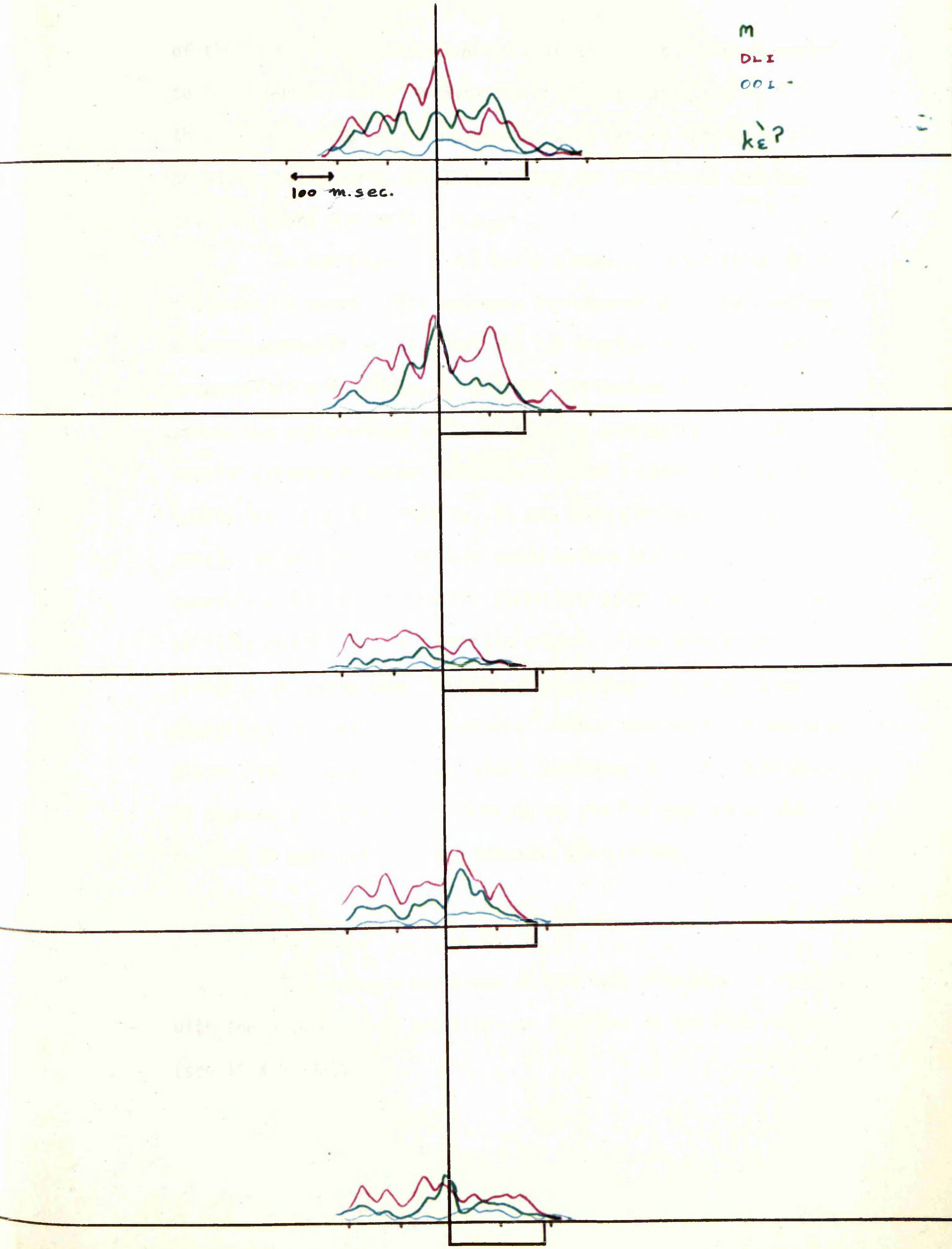
IC $\overline{X}$



IC XI



IC XII



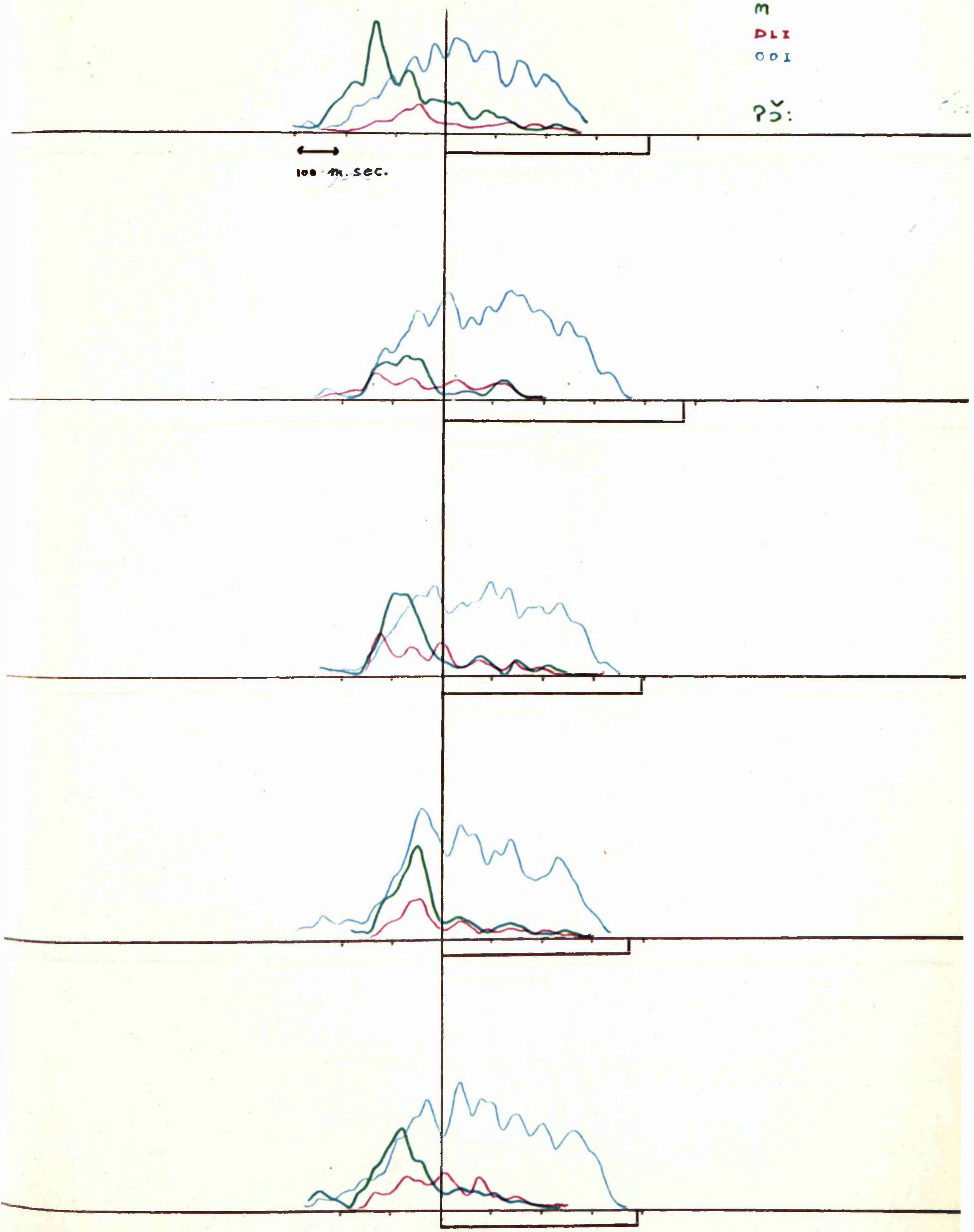
of the high peaks in relationship with the acoustic onset seemed to be irregular. The irregularity of the muscualr action for the[ɛ] utterances may be due to the weak muscle tension which probably implies that the articulation for this vowel was the most lax among the series [ɪ,e,ɛ] .

In addition, the DLI peaks always occurred prior to the mentalis peaks. This evidence corresponds with the previous electromyographic reports that the two muscles function as an antagonistic pair (Öhman, Leanderson and Persson 1966: 6; Leanderson and Lindblom 1972: 369). The termination of the vocalic utterances under investigation had a characteristic of consistency as well. That is, in the articulations of long vowels the muscular potentials ended before the ending of the acoustic signal whereas in the short articulations the muscular activity ended after the acoustic signal. This phenomenon probably indicates that the long-short pattern is based upon acoustical and perceptual features rather than upon any muscular distinction between long and short counterparts. In other words, it appears that the neural commands to the lip muscles do not operate in parallel with the commands for voicing.

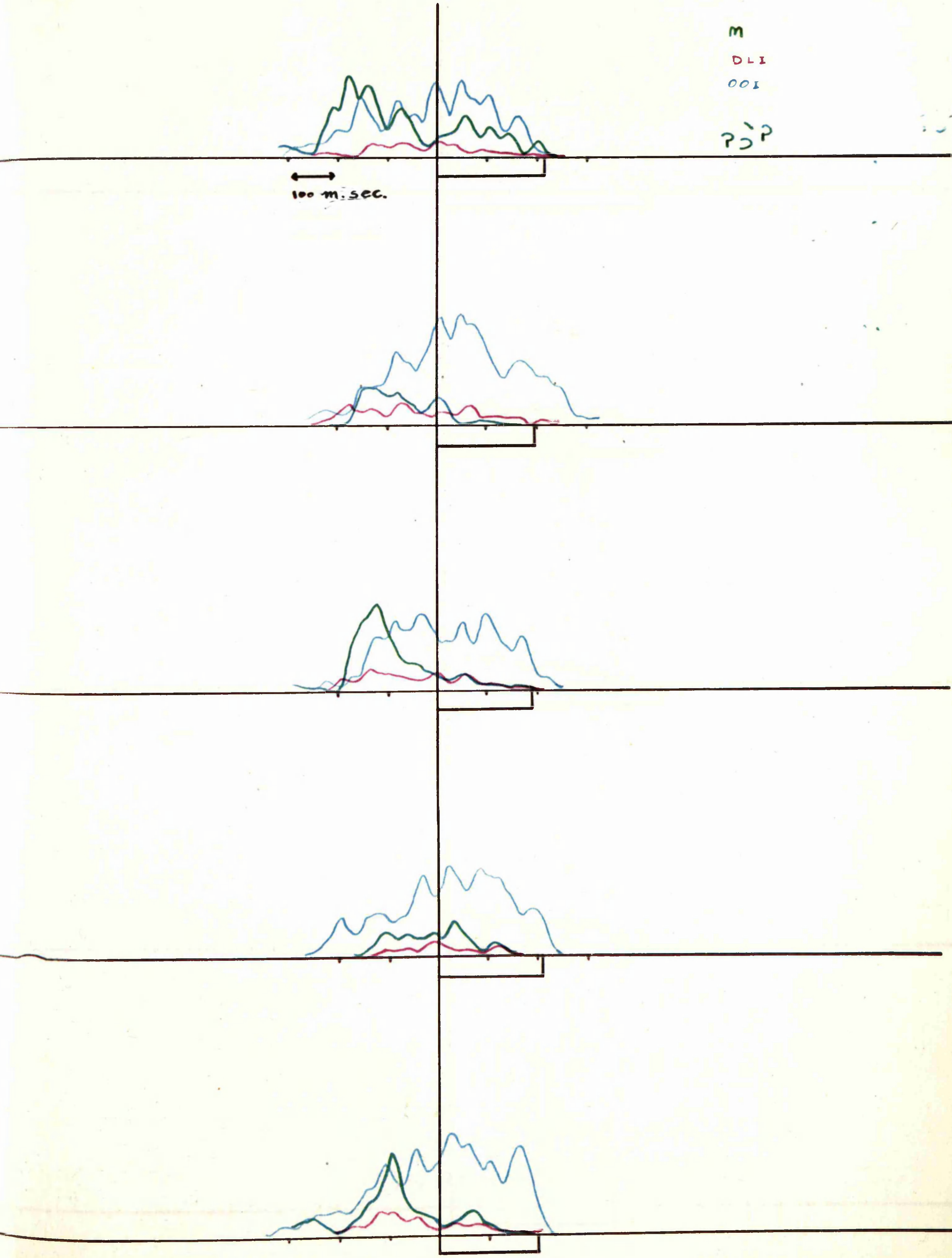
Back rounded vowels, [u: , u, o:, o, ɔ:, ɔ]

The analysis was based on the time dimension in relation with the occurrence of the muscular tensions of the high peaks. (see IC XIII-XXIV)

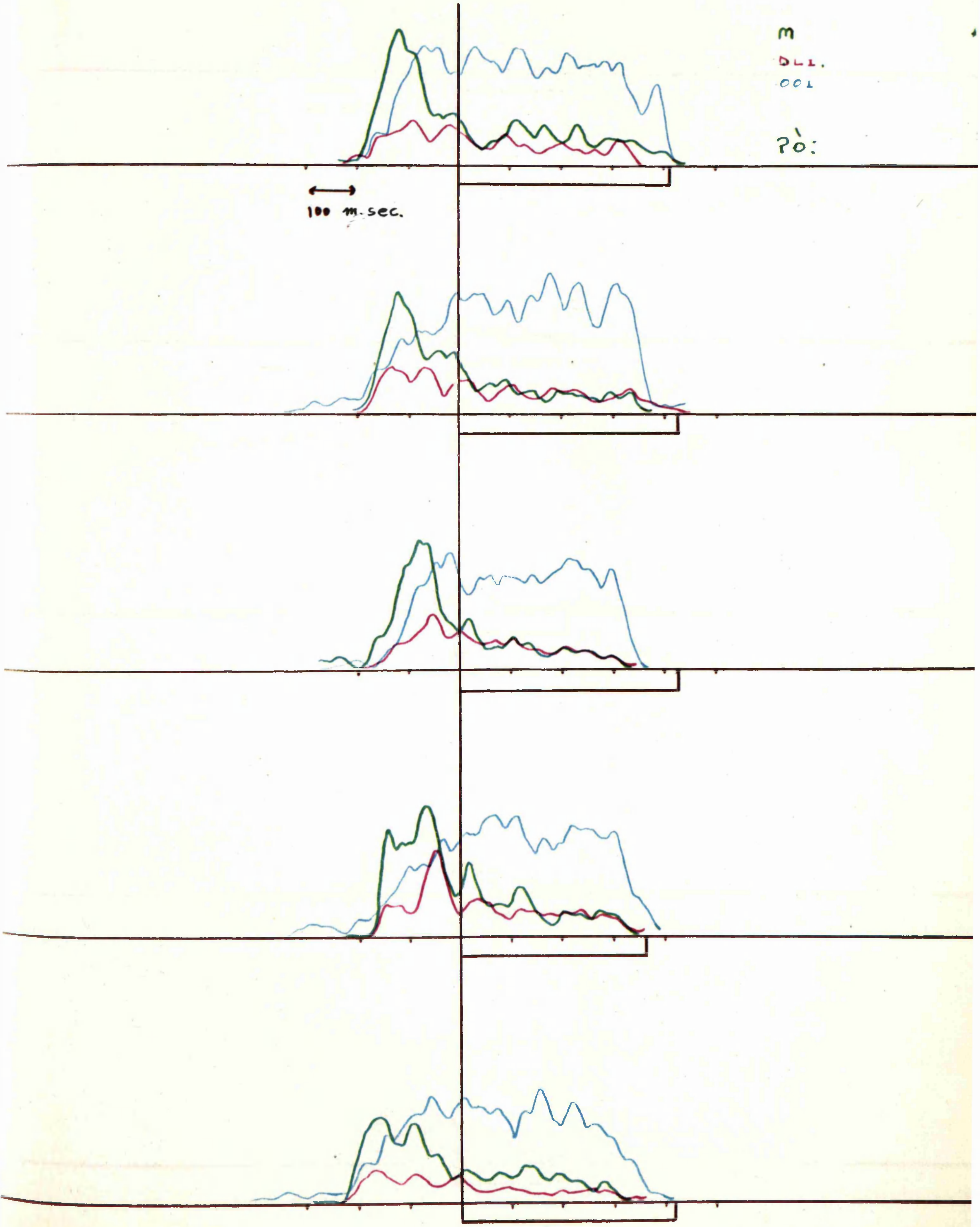
IC XIII



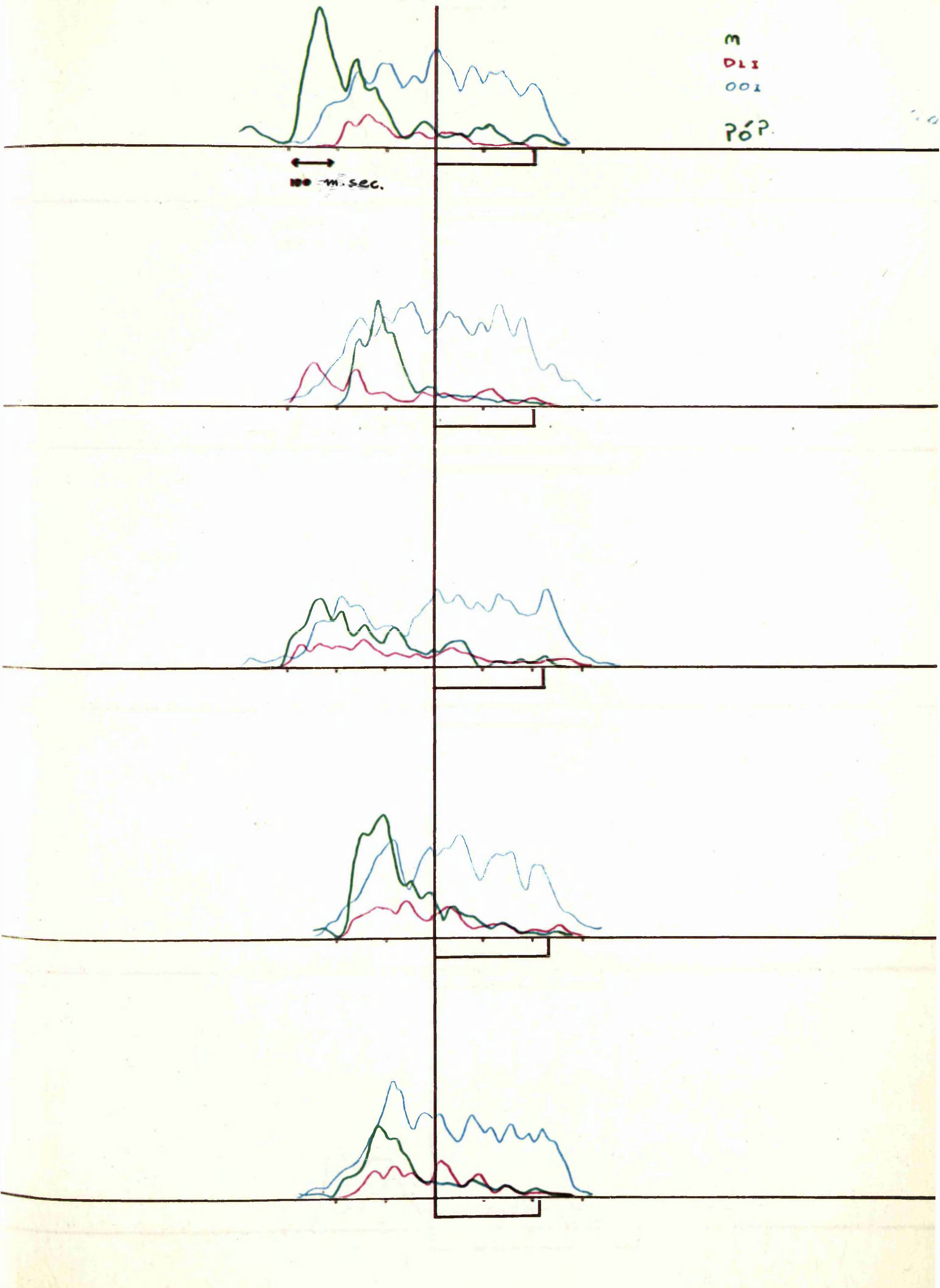
IC XIV

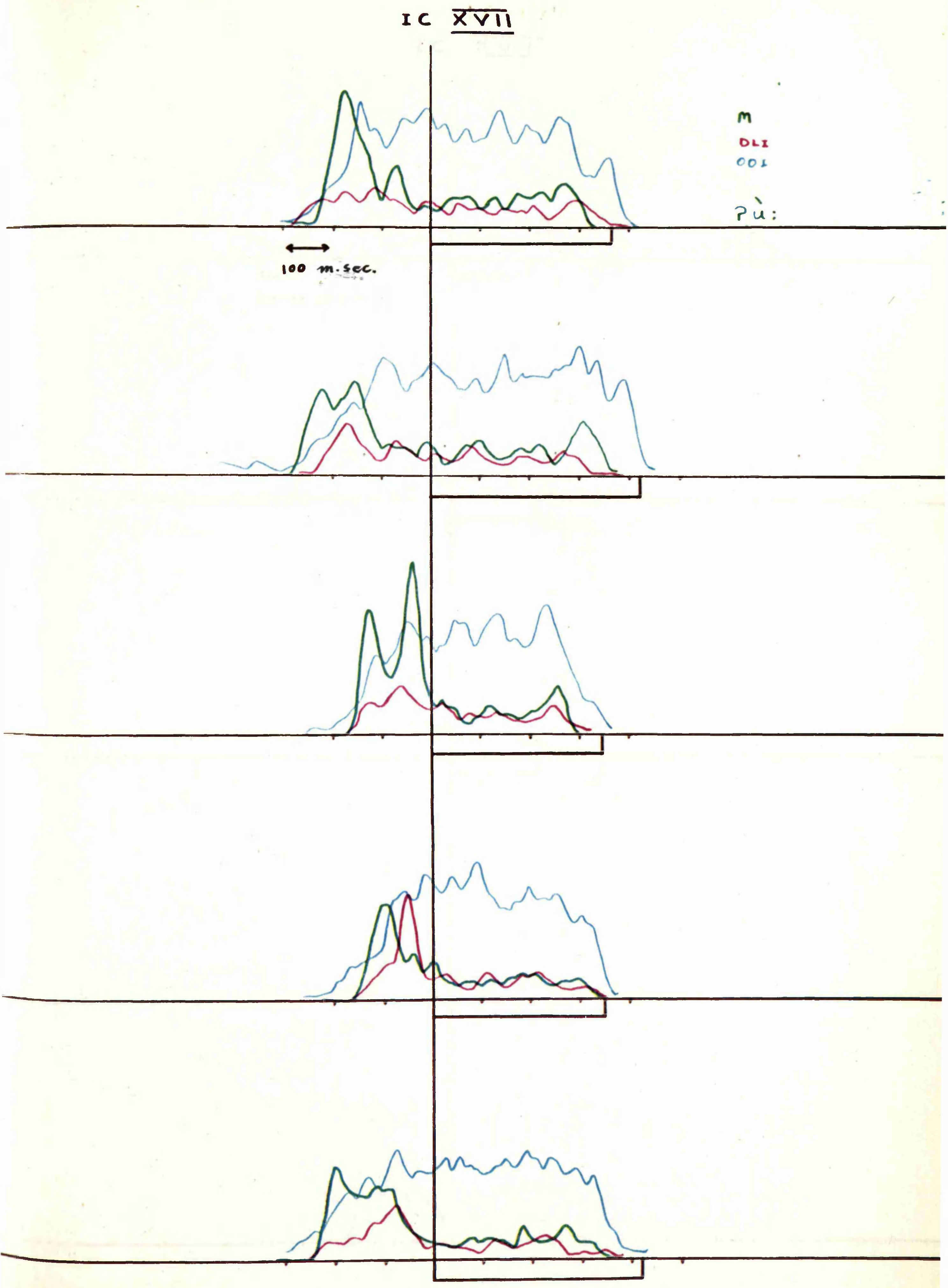


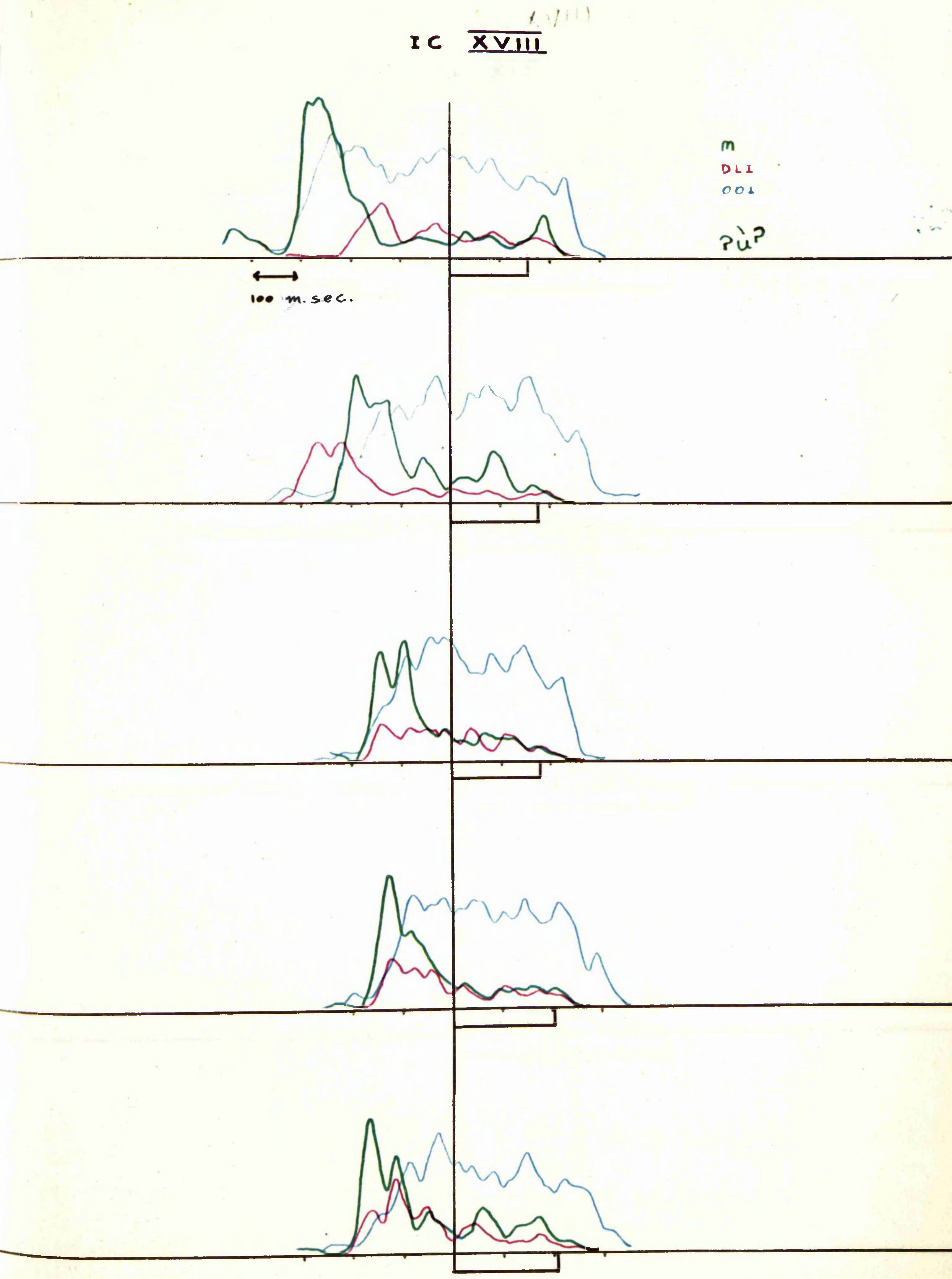
IC XV



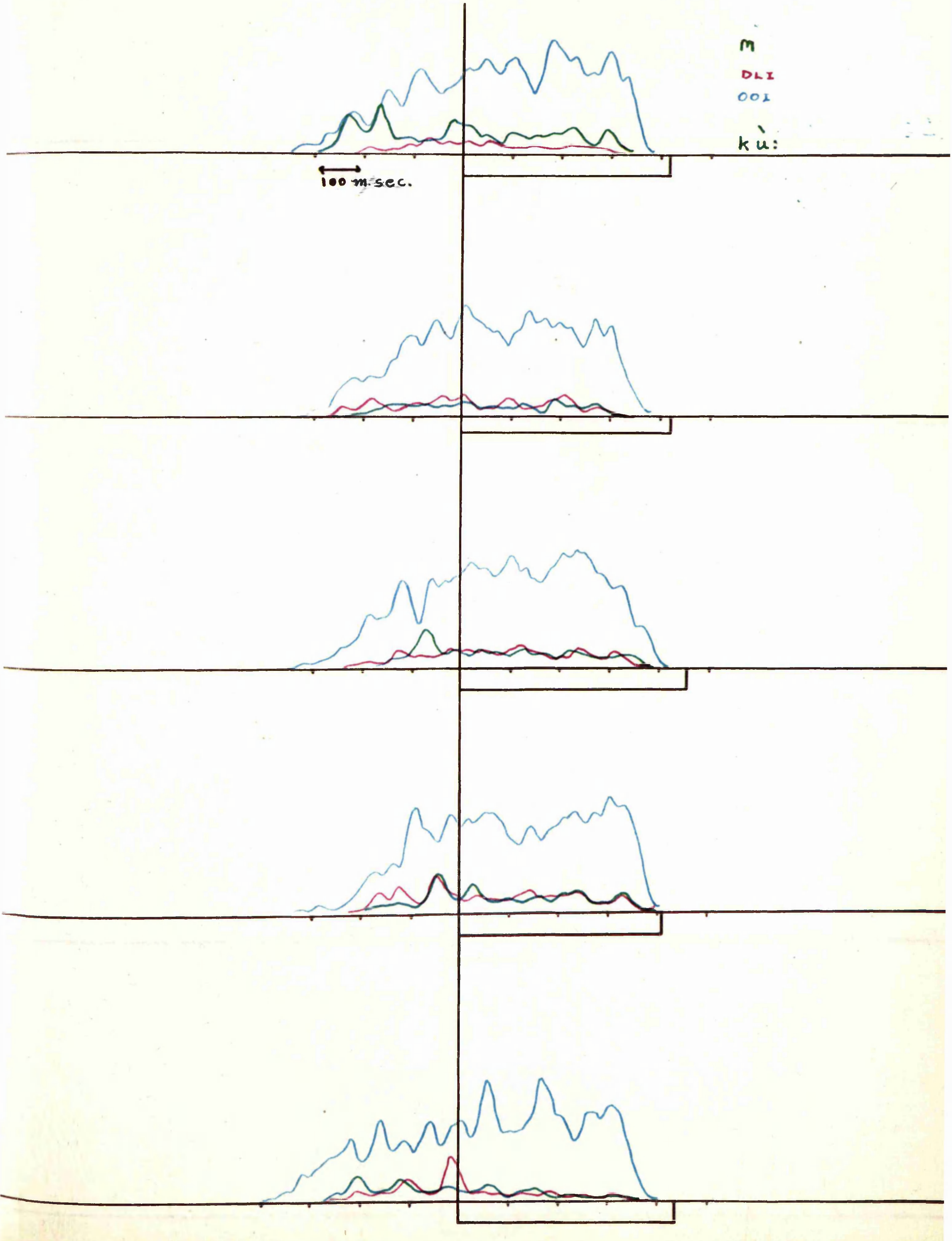
IC XVI



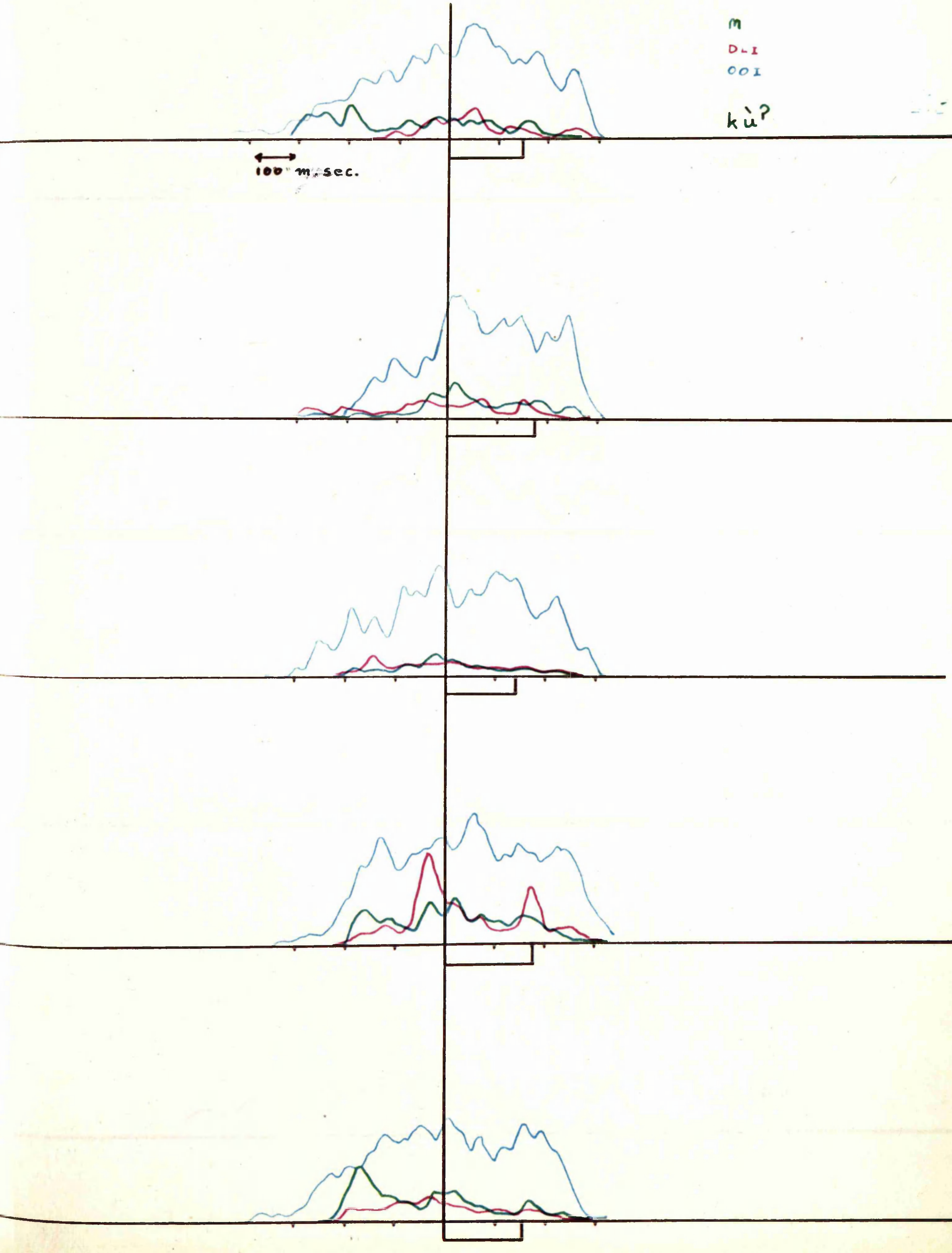

IC XVII
m
DLI
OOI
ʔù:
100 m.sec.


IC XVIII
m
DLI
OOL
pùp
100 m.sec.

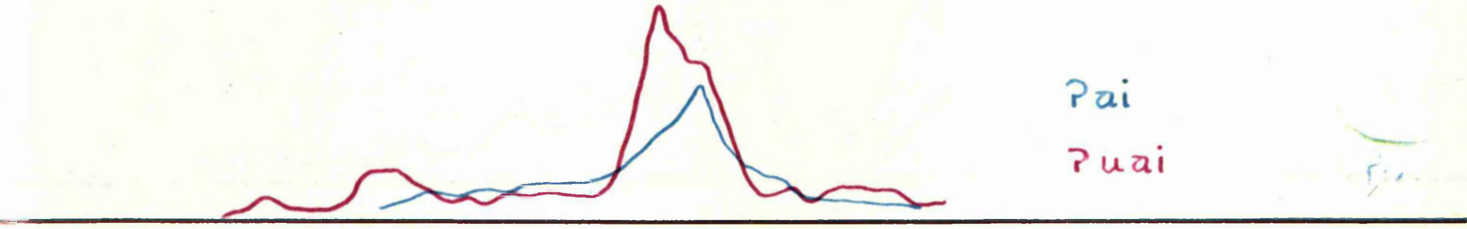
IC $\overline{\text{XIX}}$

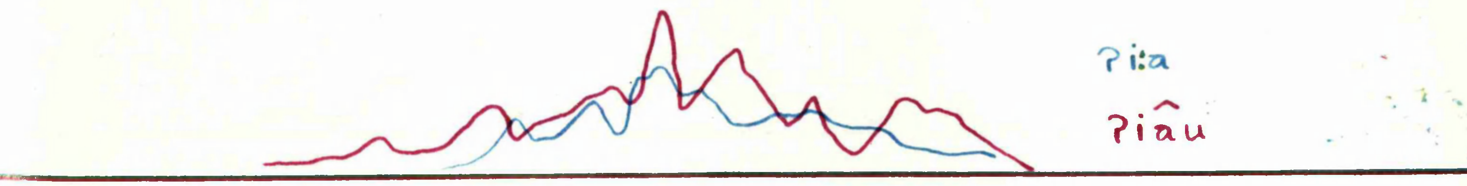


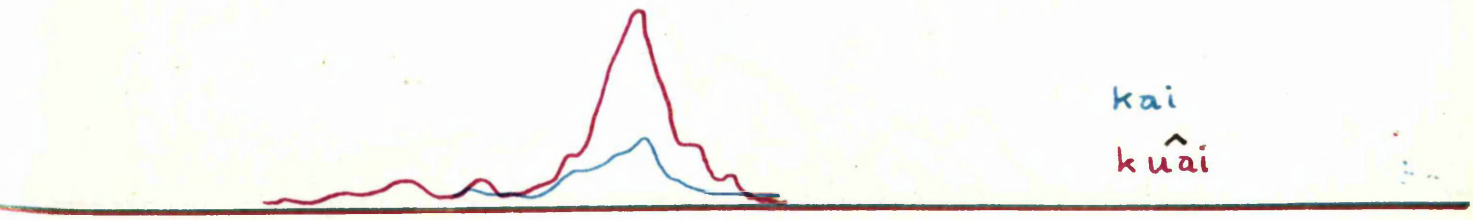
IC XX

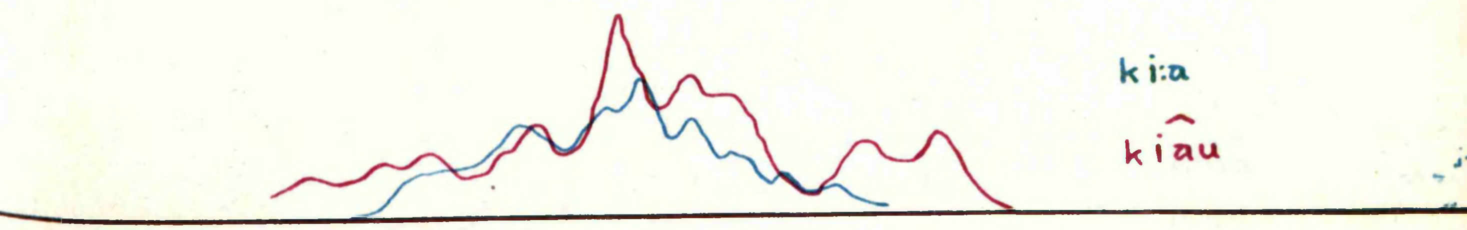


AIC $\overline{XXI}$

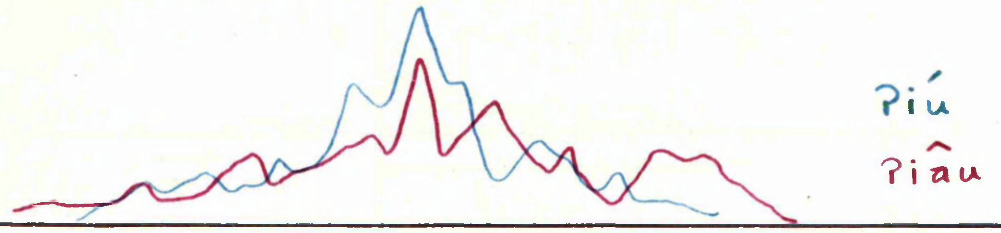


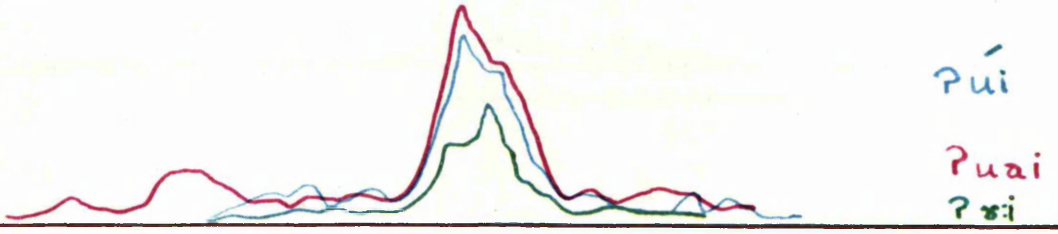


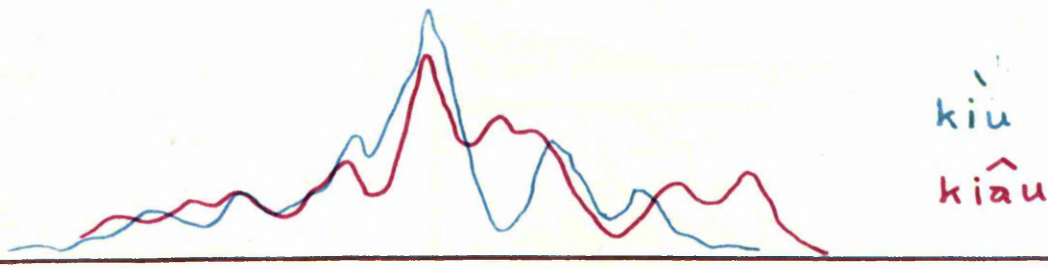


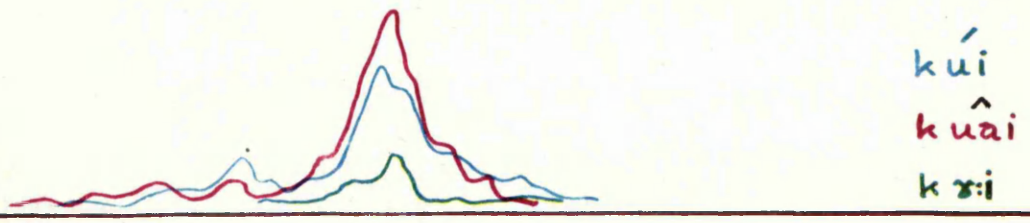


AIC XXII

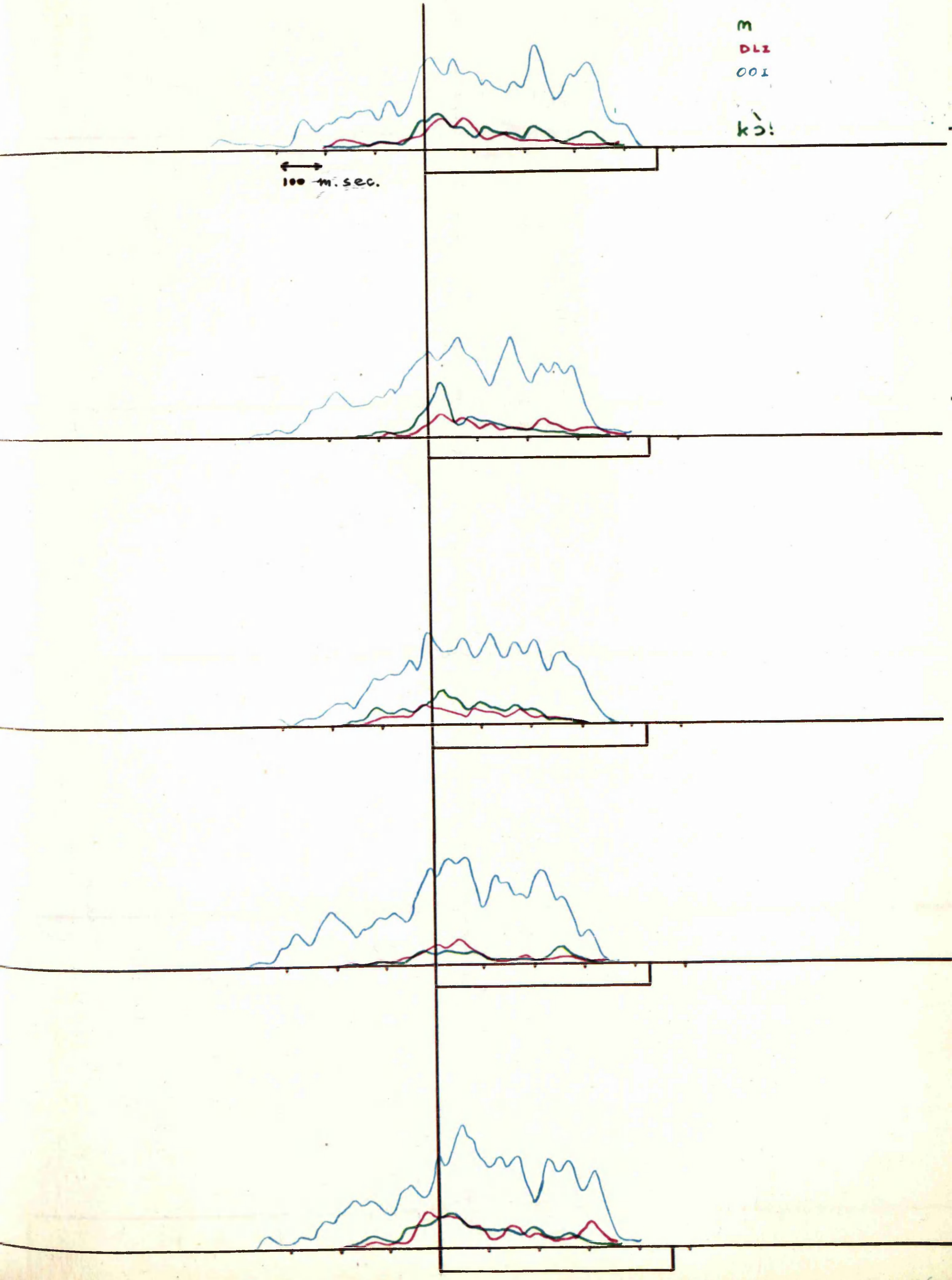




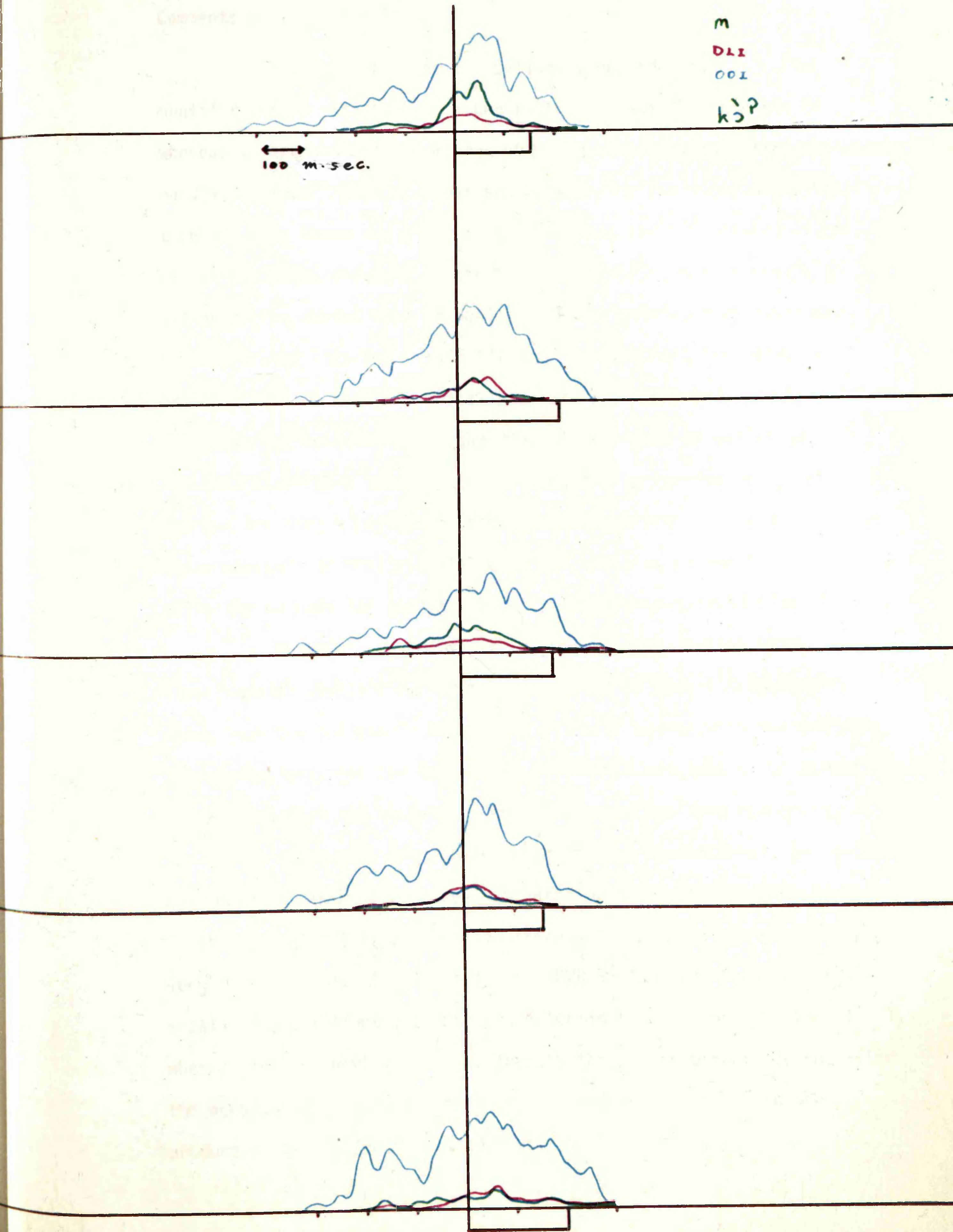




IC XXIII



IC XXIV



Comments on IC XIII-XXIV

It is seen that in the syllables preceded by [?] the mentalis action potentials reached their peak earlier than the OOI, whereas in the syllables preceded by [k] the mentalis action potential hardly occurred. When a comparison between the two types of syllabification was made there was a distinction in that the OOI integrated curves of the syllables preceded by the [?] rose abruptly, but in the [k] syllables the curves rose gradually. This significant evidence may be interpreted into two possibilities. One is that, the evidence probably implies that the mentalis muscle was functioning as an initiator in the abrupt contraction of the OOI. Another may be explained that for the [?] syllable there is only one gesture occurring in the oral cavity, whereas for the [k] syllable there are two gestures. Accordingly, the motor command, for the [?] syllable, to the mentalis presumably is not blocked, while the command, for the [k] syllable, to the mentalis is blocked.

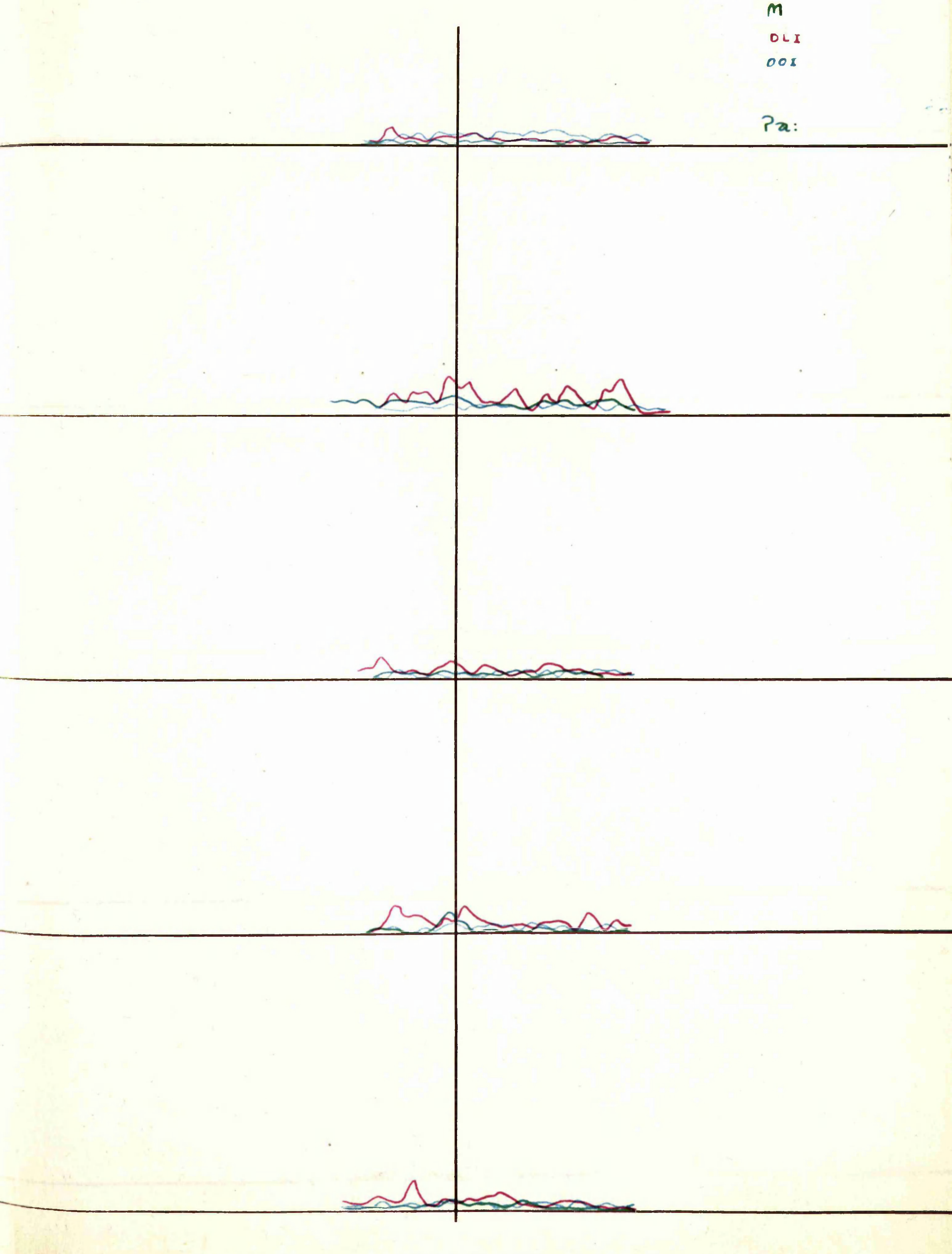
Moreover, the mentalis was more active for the utterances of close rounded vowels than for the open ones. Since it is generally known that the DLI muscle is antagonistically paired with the mentalis, in rounding gestures the DLI action potentials are seen to be occurring in parallel with the mentalis. There are also the same phenomena, as far as the occurrence of high muscular tension is concerned, in that the high peaks of integrated curves appeared prior to the acoustic signal in the case of the short vocalic articulations and posteriorly for the long vocalic ones. Additionally, the EMG action potentials of the long vocalic articulations end before the termination of the acoustic signal, whereas in the short vocalic utterances the action potentials end after the acoustic activity; the same type of evidence is found in the production of the front unrounded vowels.

In addition, from IC XIII-XXIV DLI activity also occurred for rounding. According to Hadding et al. (1970, 1976) DLI activity was found for rounding, tight closure of the lips and/or extreame protrusion. It was suggested that the DLI muscle is active for rounding in supporting the soft tissues around the OOI, or DLI activity may represent co-contraction. However, the DLI activity in the present data (IC XIII-XXIV) only occurred in paralell with the mentalis muscle activity. The evidence supports the suggestion, Öhman et al. (1966), Kennady and Abb (1975), that the DLI functions antagonistically to the mentalis.

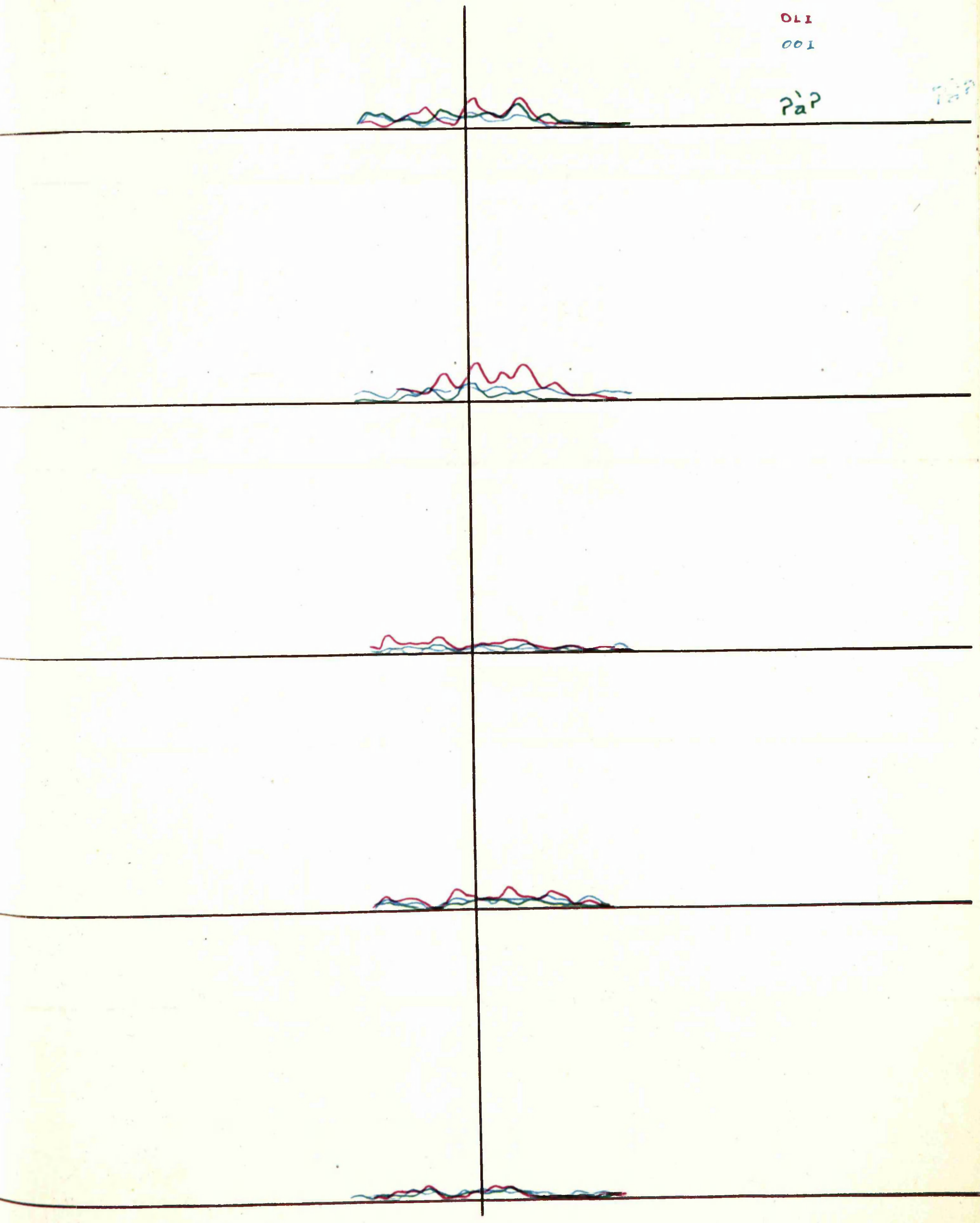
Unrounded vowels [a:, a , ɯ:, ɯ , ɤ:, ɤ]

According to traditional classifications, this group of vowels is categorized as central vowels (Haas, 1956) or as back central vowels (Anthony, French and Warotamasikkhadit, 1968). However, from the electromyograms of the [a: ,a] there is evidence of DLI action potentials, whereas there is almost none in the articulations for the [ɯ:, ɯ] and the [ɤ:, ɤ] This suggests that [a:, a]should not be classed along with [ɯ:, ɯ , ɤ:, ɤ]. The DLI integrated curve evidence appears to suggest that[a:, a] should be categorized with the front vowel group. Meanwhile the integrated curves of [ɯ:, ɯ , ɤ:, ɤ] seem to suggest that this group of vowels should be grouped as neutral vowels, i.e. non-front and non-back (see IC XXV-XXXVI).

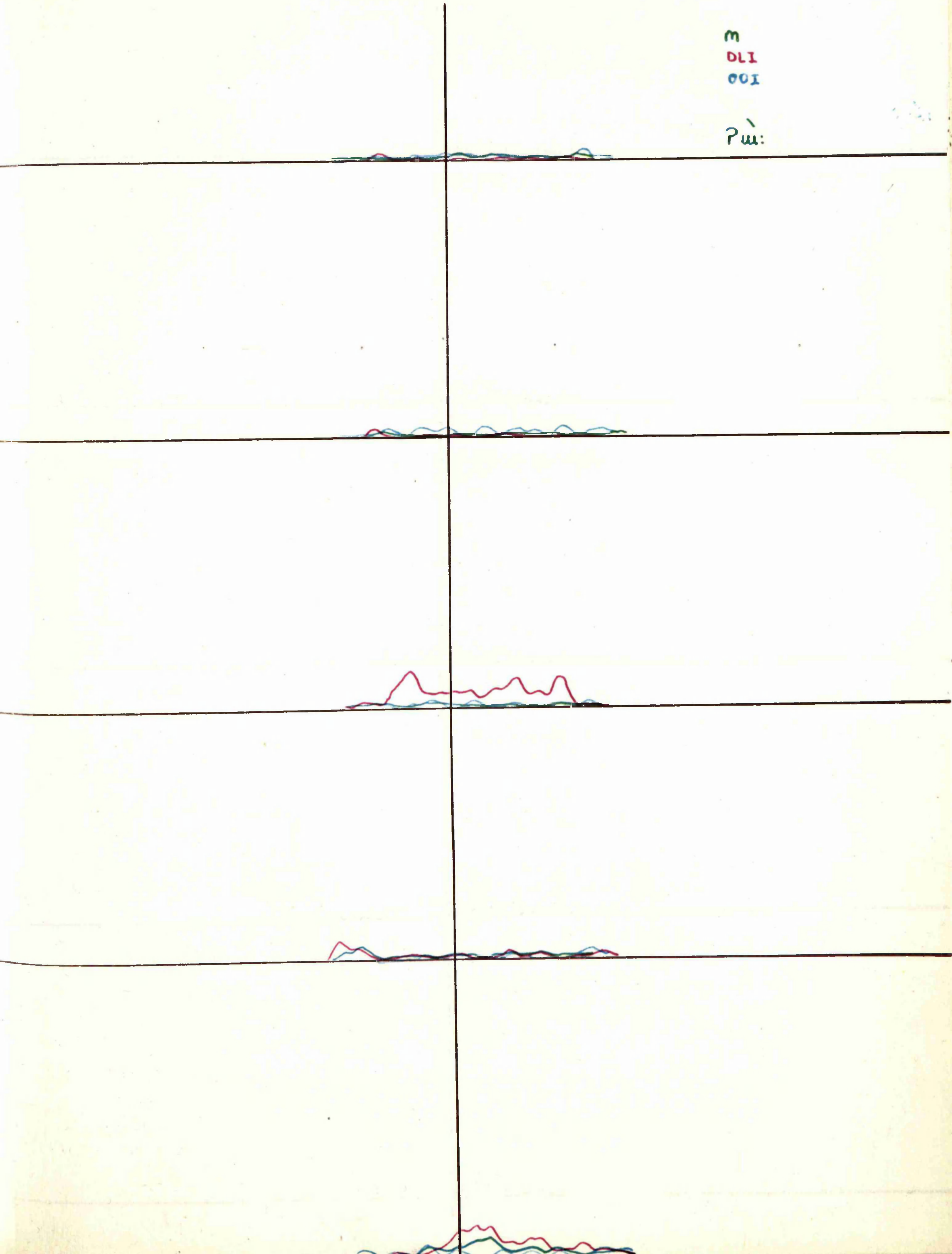
IC $\overline{\text{XXV}}$



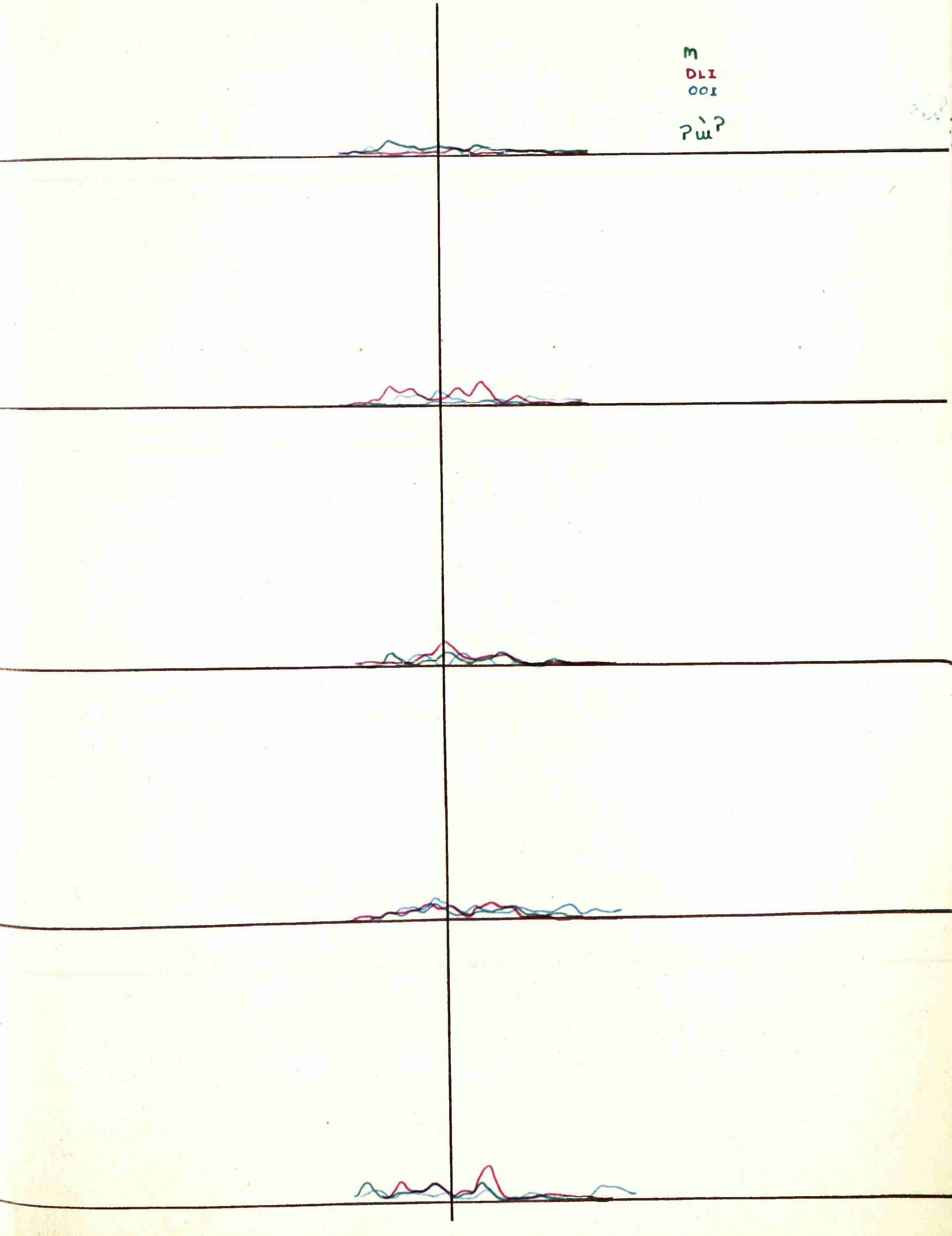
IC XXVI



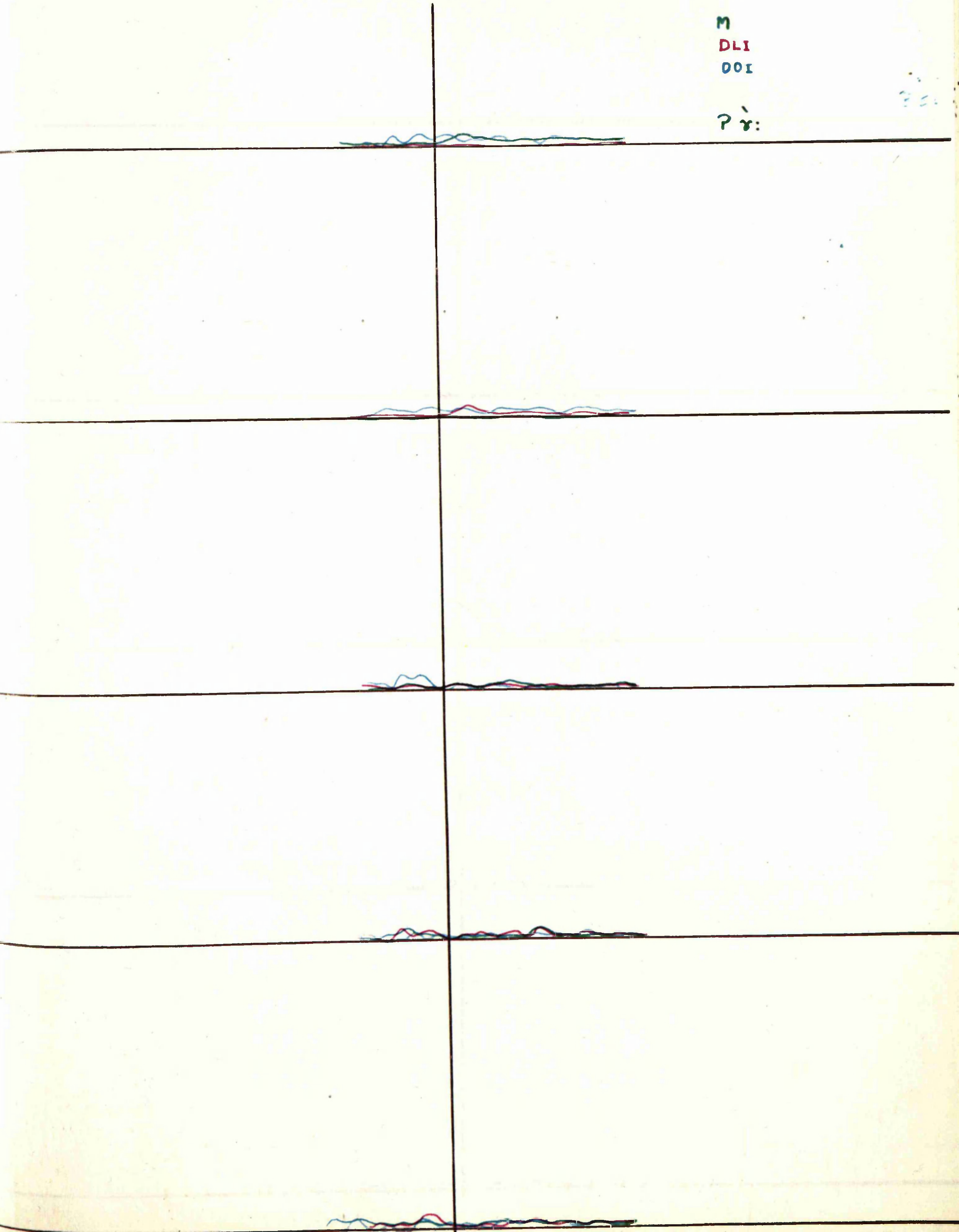
IC XXVII



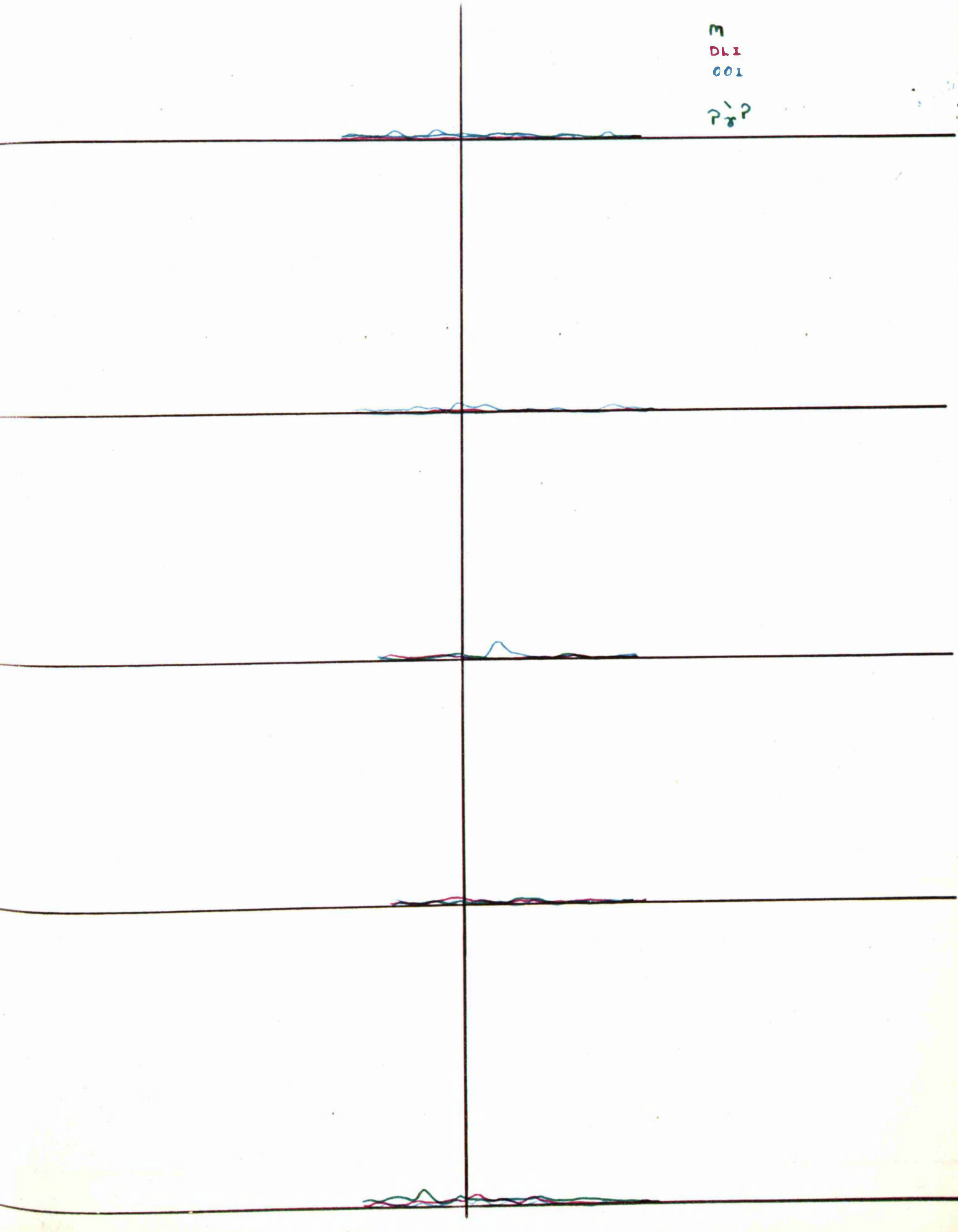
IC XXVIII



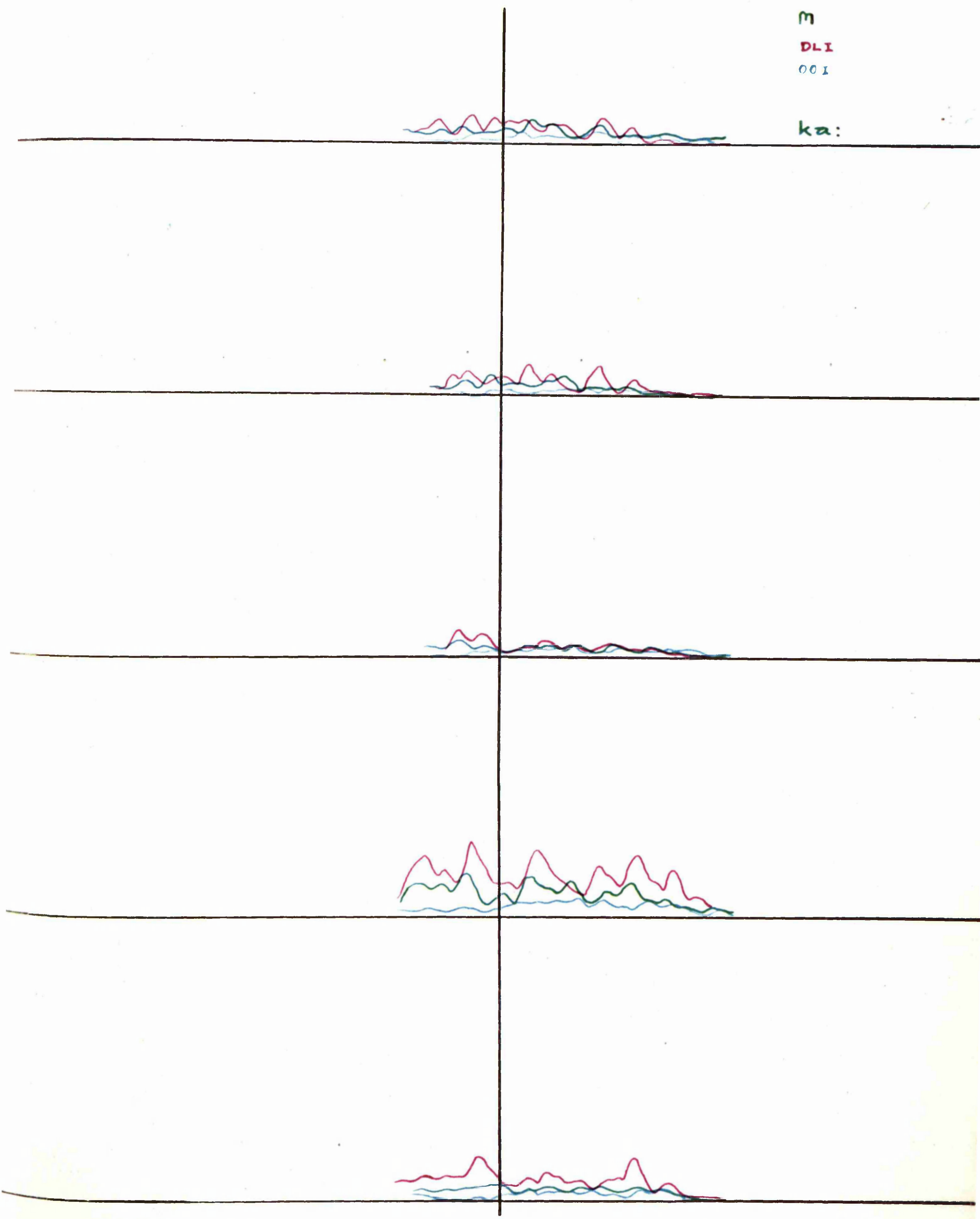
IC XXIX



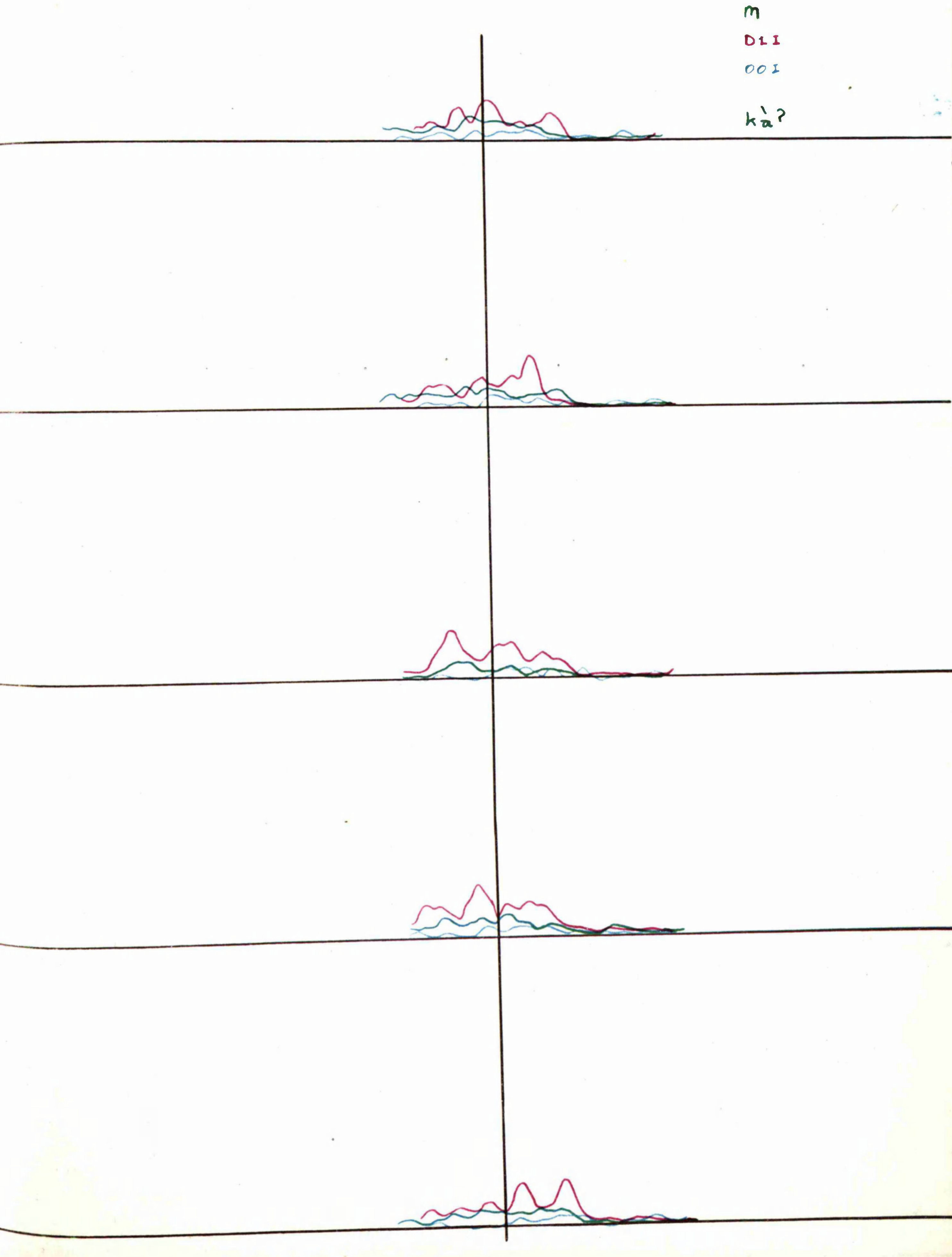
IC XXX



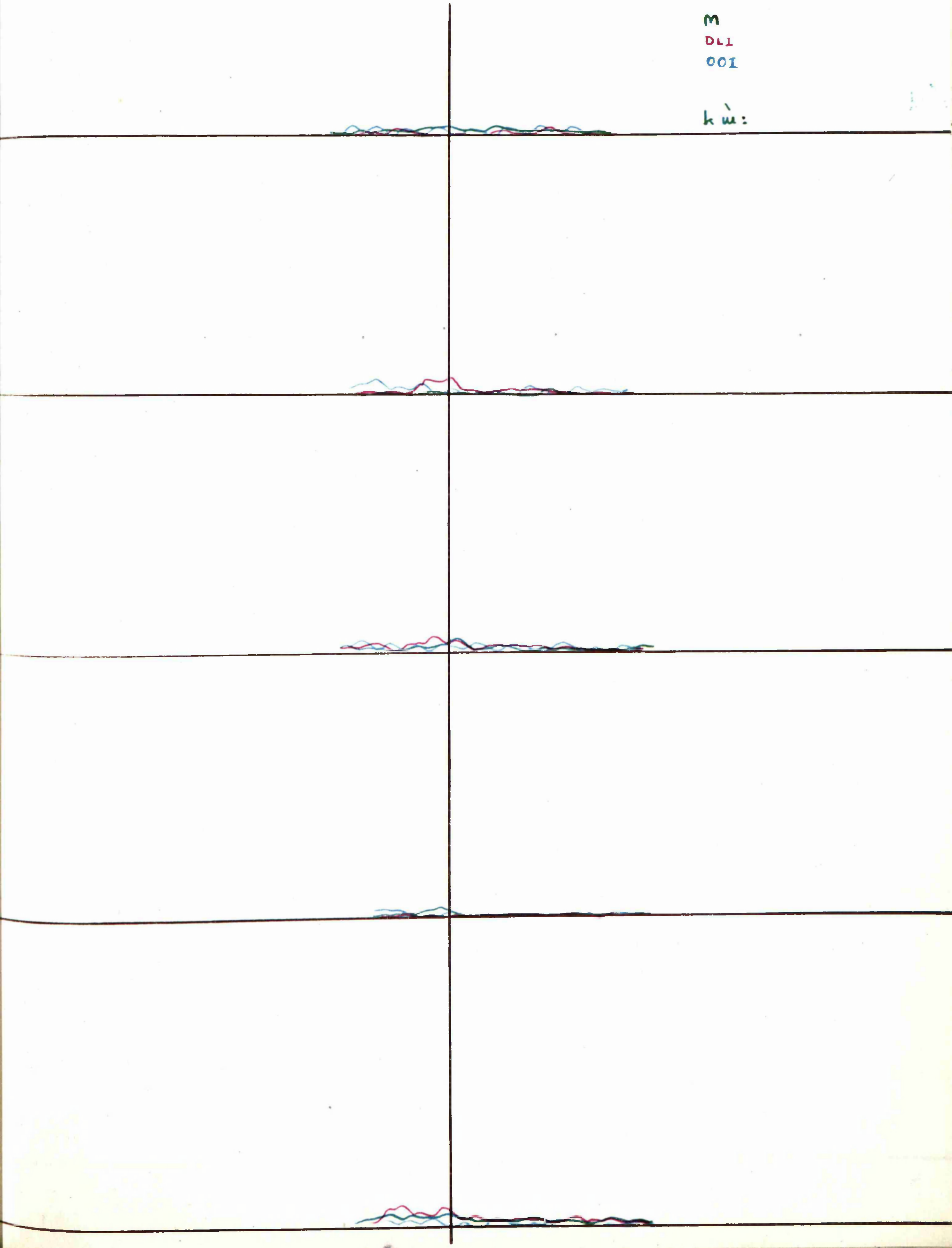
IC XXXI



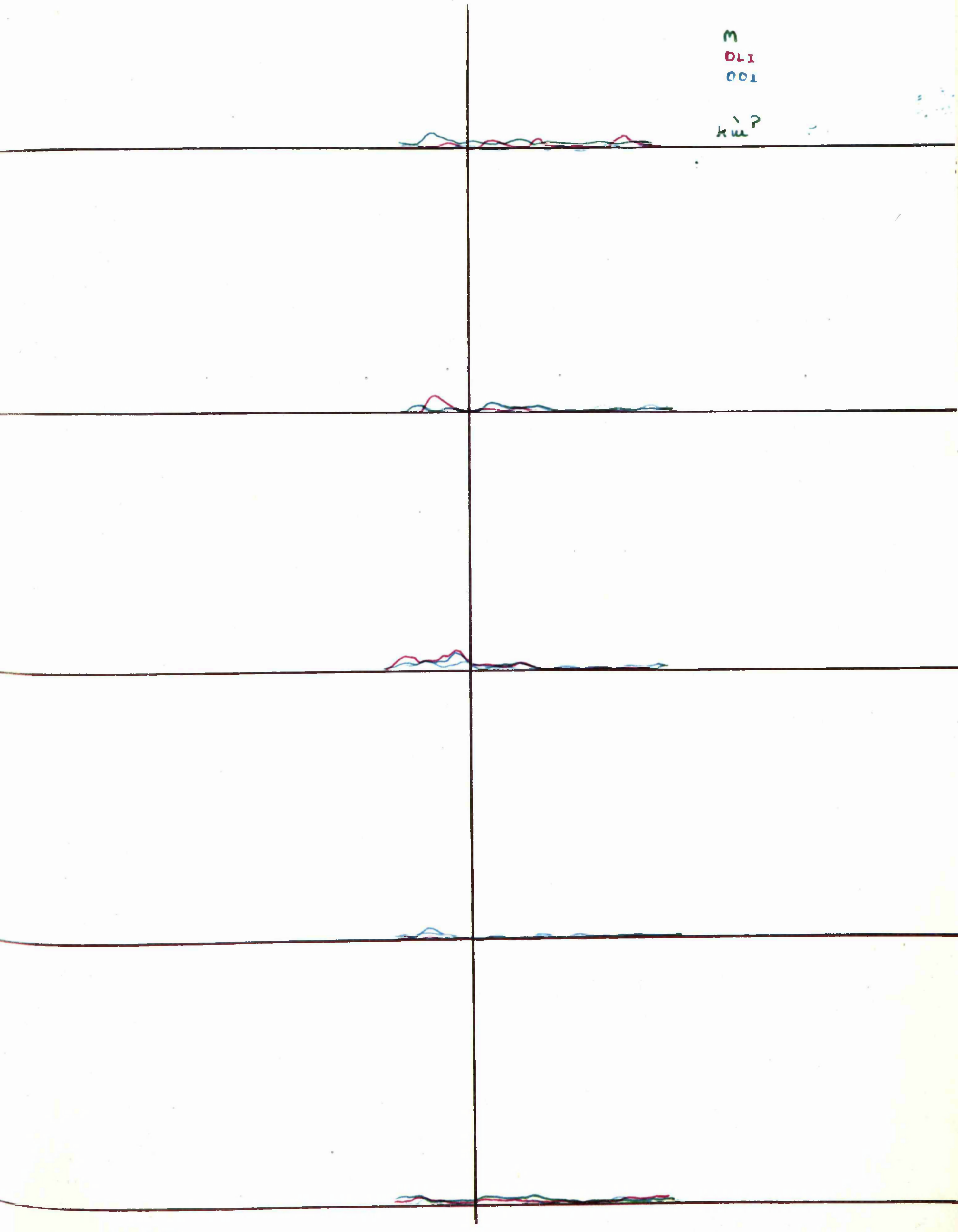
IC XXXII



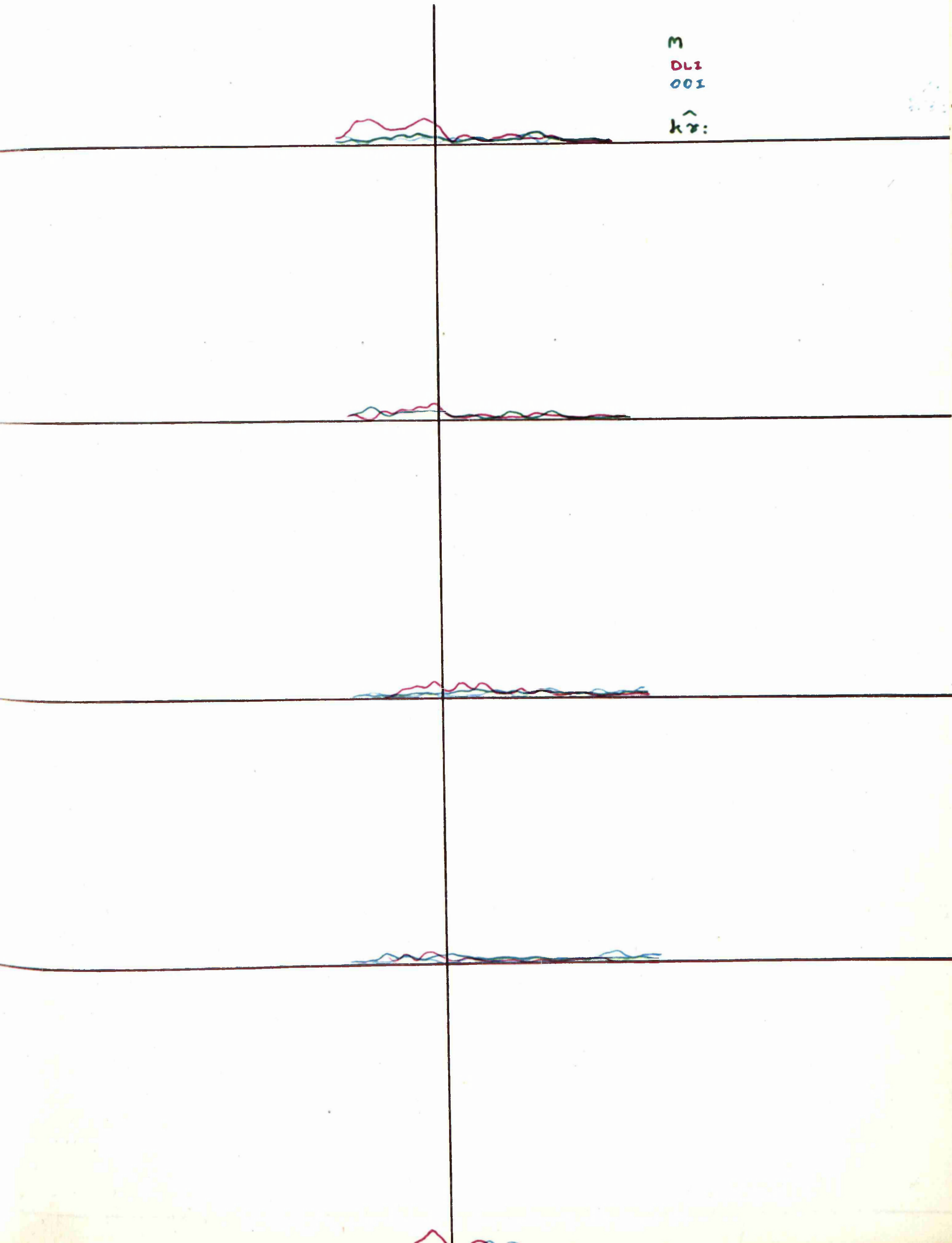
IC XXXIII



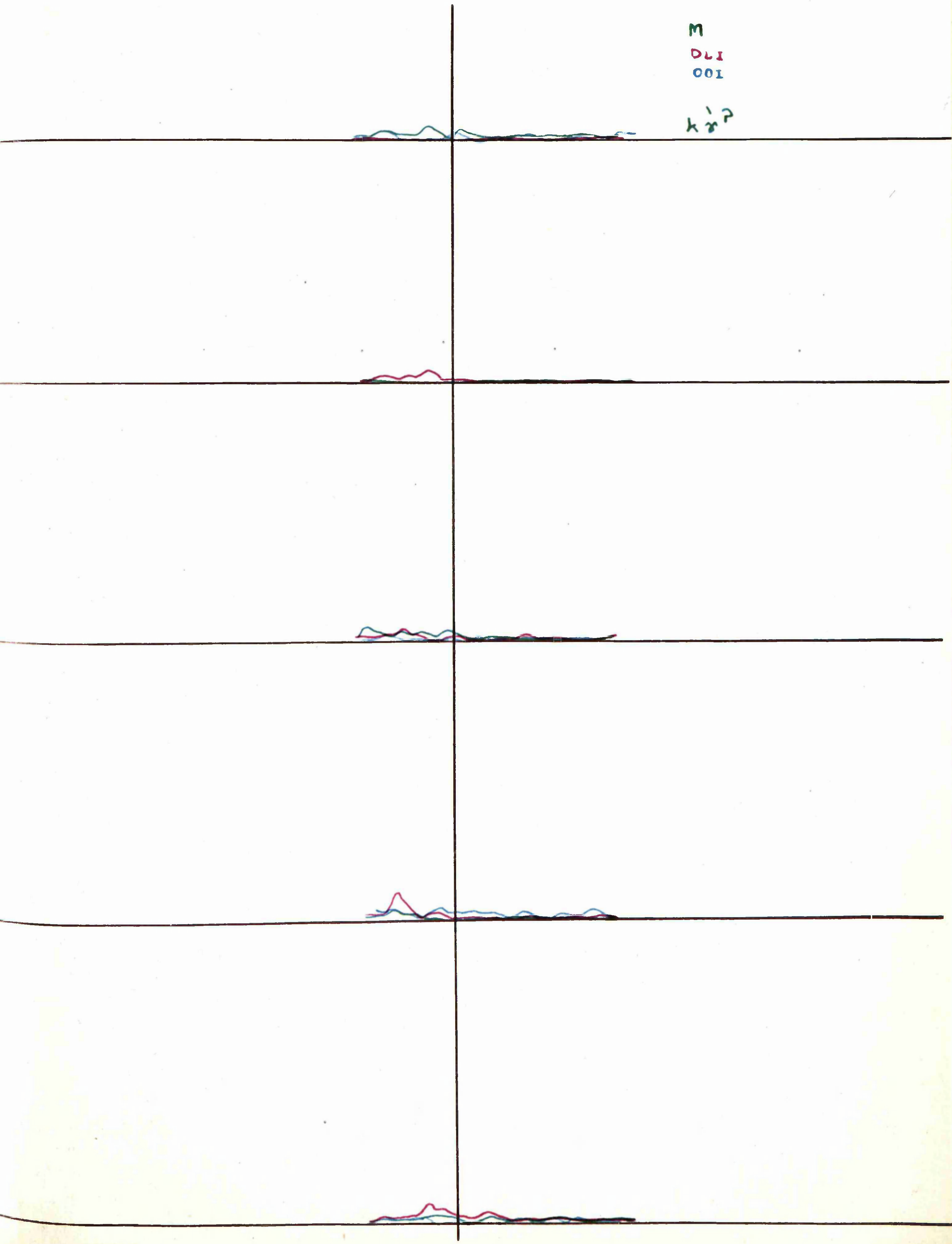
IC XXXIV



IC $\overline{\underline{XXXV}}$



IC XXXVI



Coordination in diphthongs

The data presentation was arranged according to the labial gestures. On the basis of the gestures, diphthongs are categorically presented in two groups: one with lip-spread ending: [uɨ , o:ɨ , ɔɨ , ua], the other with lip-round ending: [iu , eu , ɛu , ɛ:u , au]. (see IC XXXVII-LII)

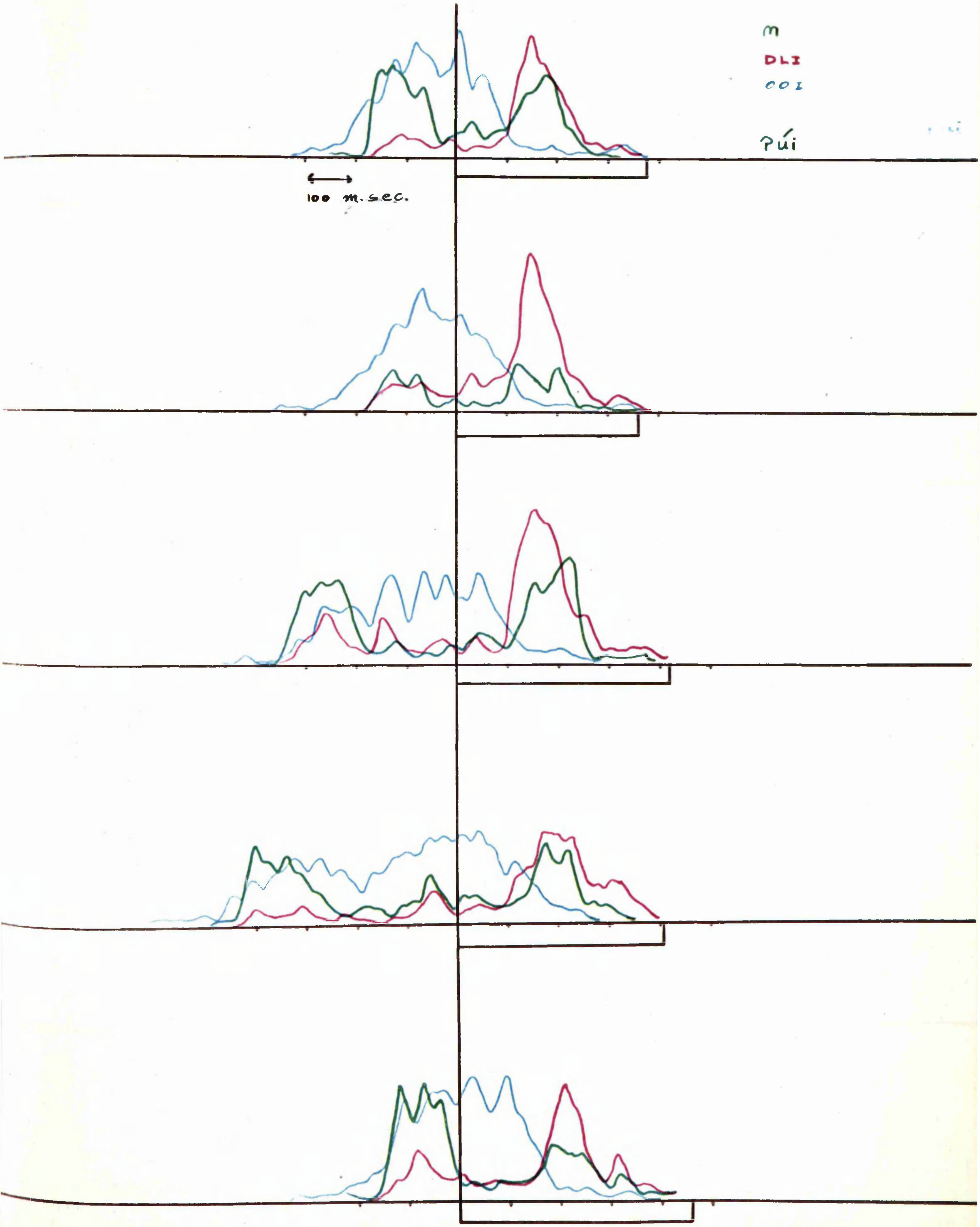
Comments on IC XXXVII-LII.

In the spread ending group, [uɨ , o:ɨ , ɔɨ , ua] there were muscular potentials which indicated that the so-called "prespeech activity" of the DLI started during the OOI activity. The mentalis was very active in both the spread and round gestures but this activity appears to differ significantly in relation to the onset of the activity of the DLI and the OOI. That is, in the case of spread gesturing, the mentalis muscle was activated either at the same time as the DLI or slightly delayed. On the contrary, in round gesturing where abrupt contraction is required the mentalis reached the peak earlier than the OOI did.

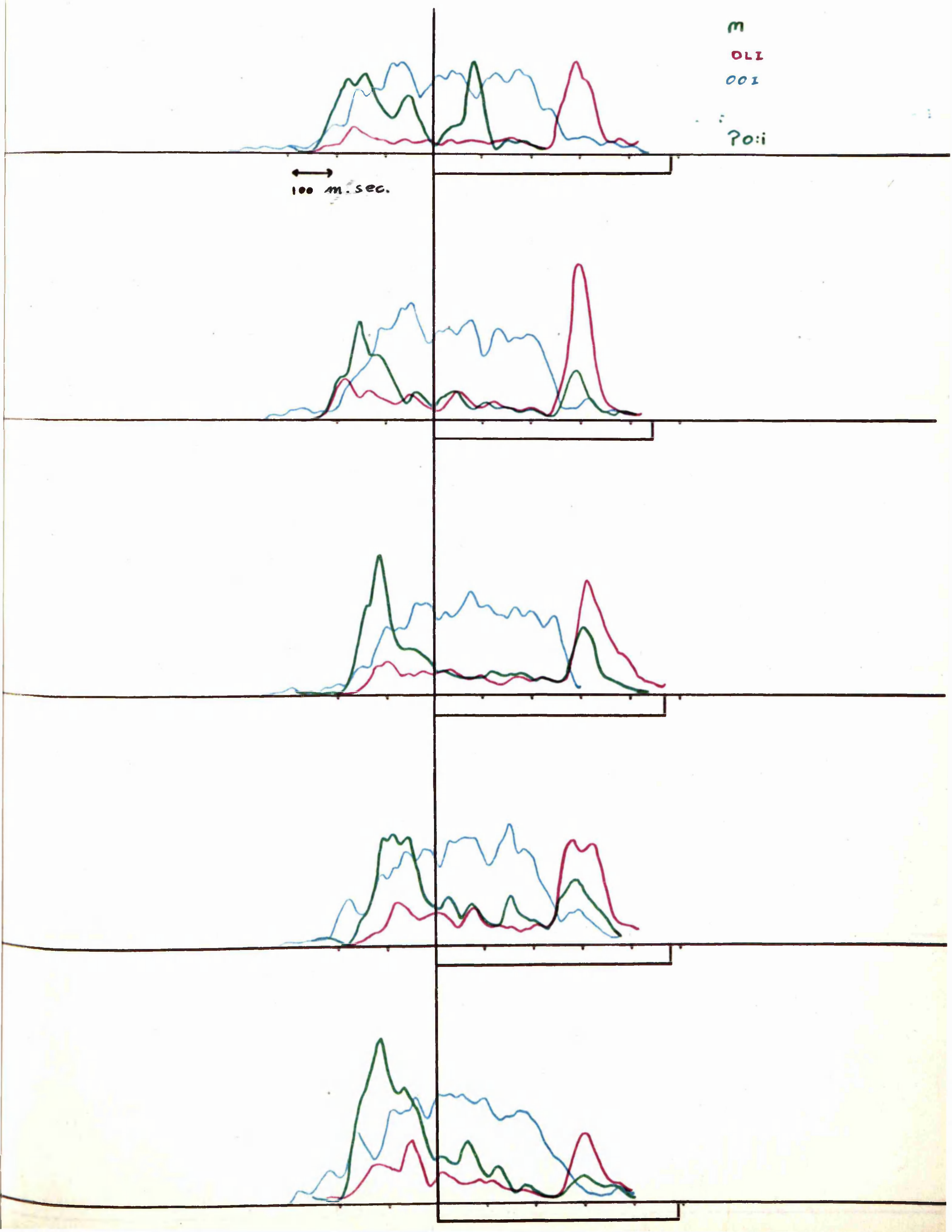
In the round ending group, the prespeech activity of the OOI also started during the DLI activation. In short, the muscular coordinations in diphthongs appear to be in a time overlapping pattern.

There is also evidence that the muscular activity ended before the acoustic signal. This type of termination is similar to that of the long monophthongs.

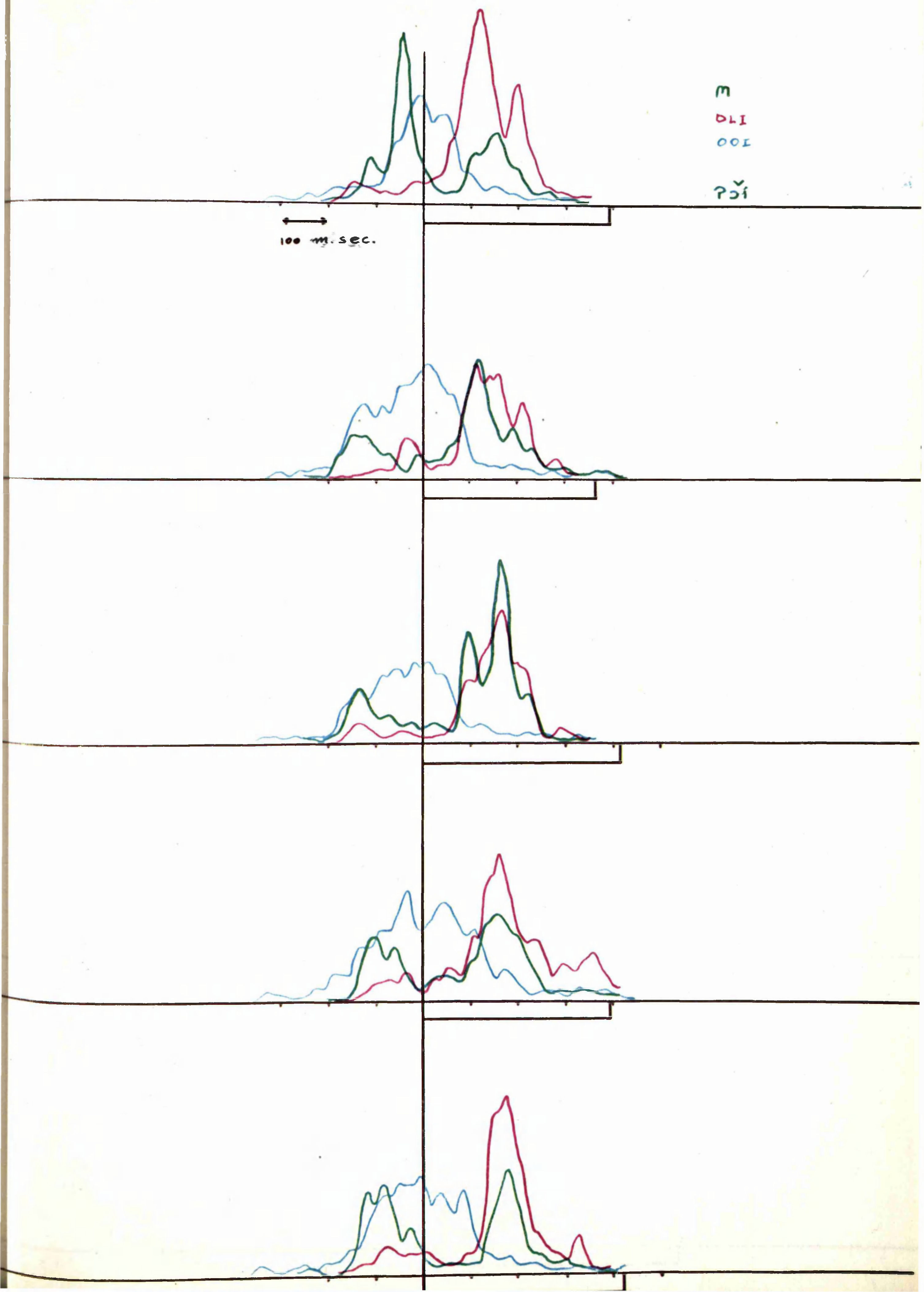
IC XXXVII

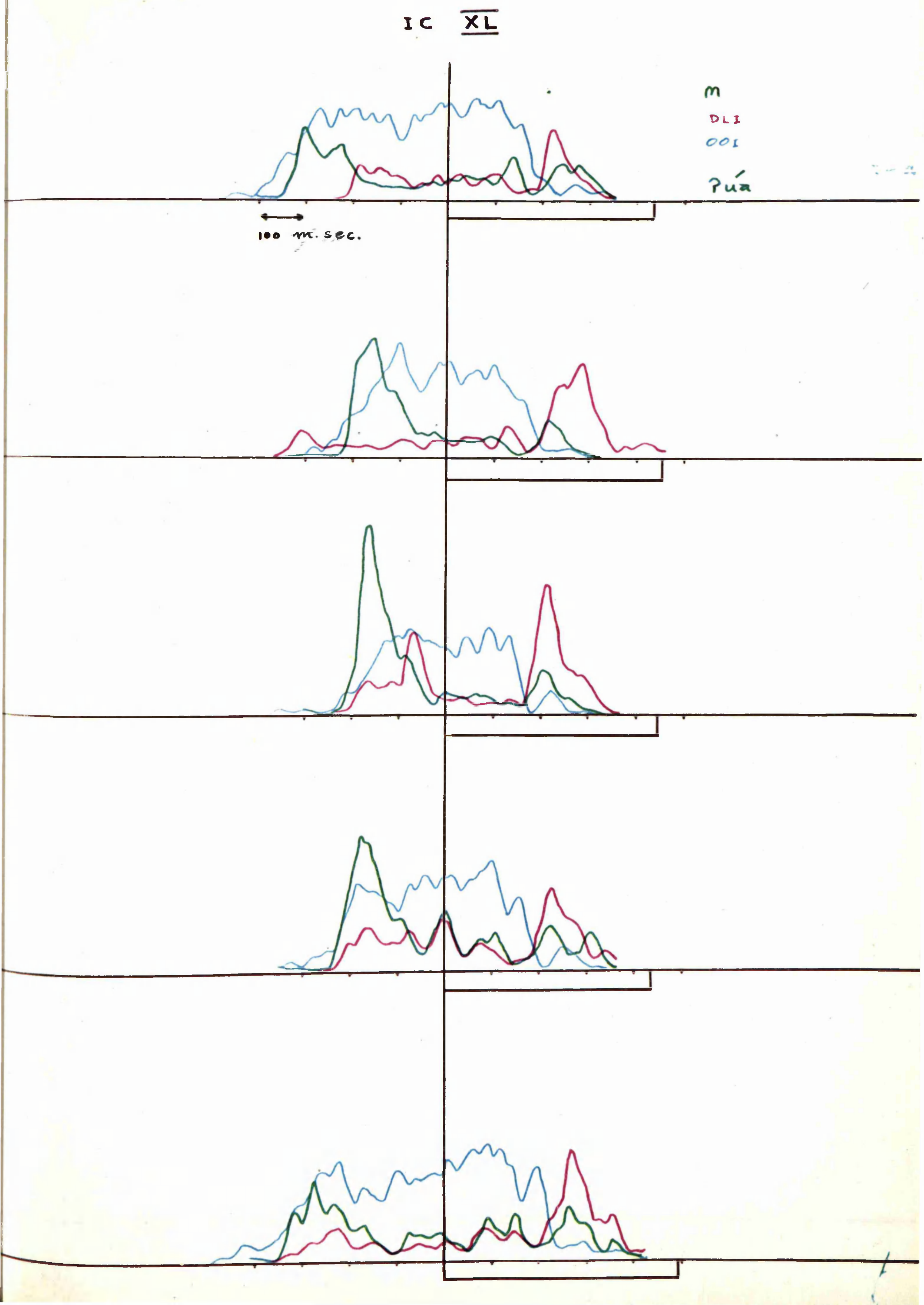


IC XXXVIII

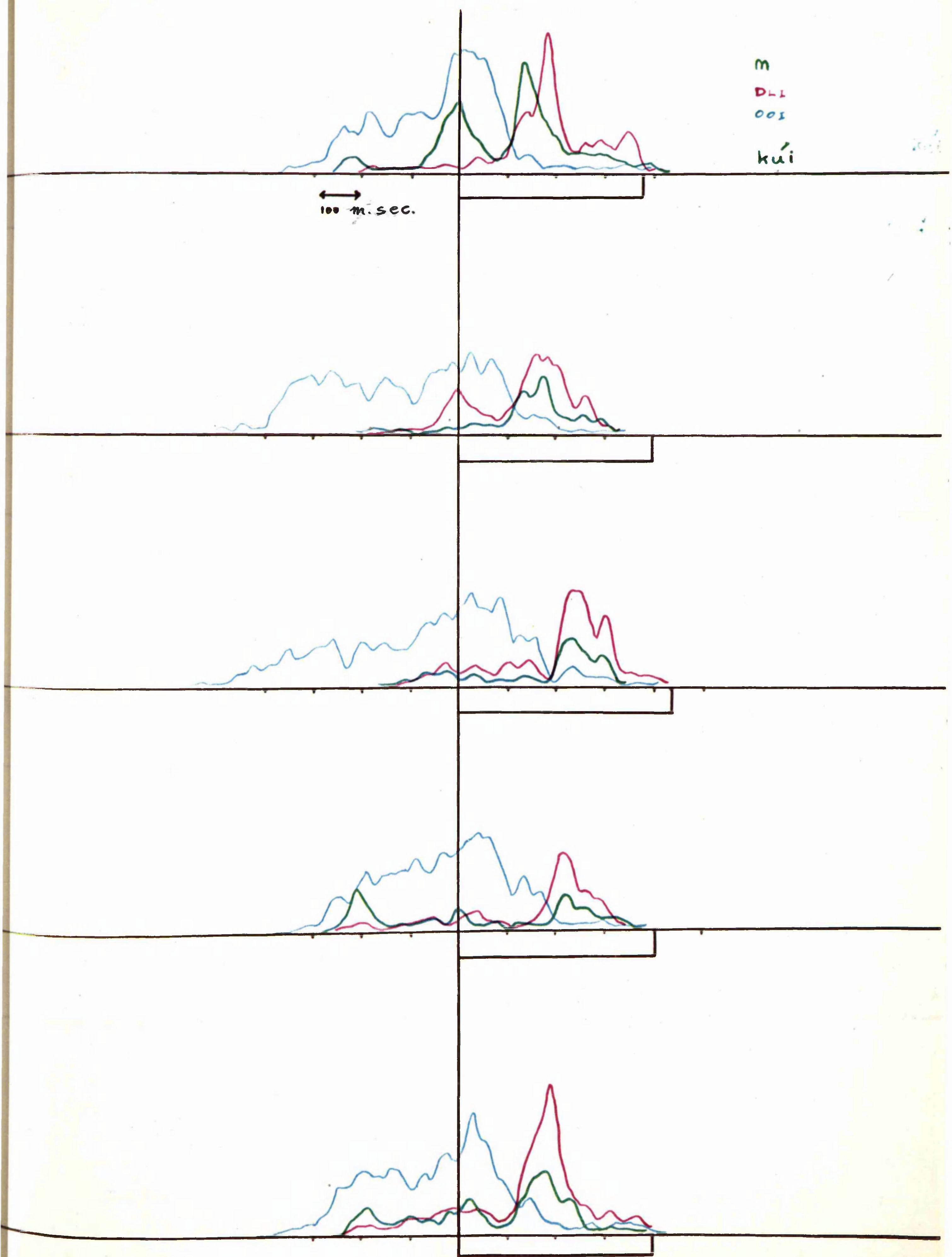


IC XXXIX

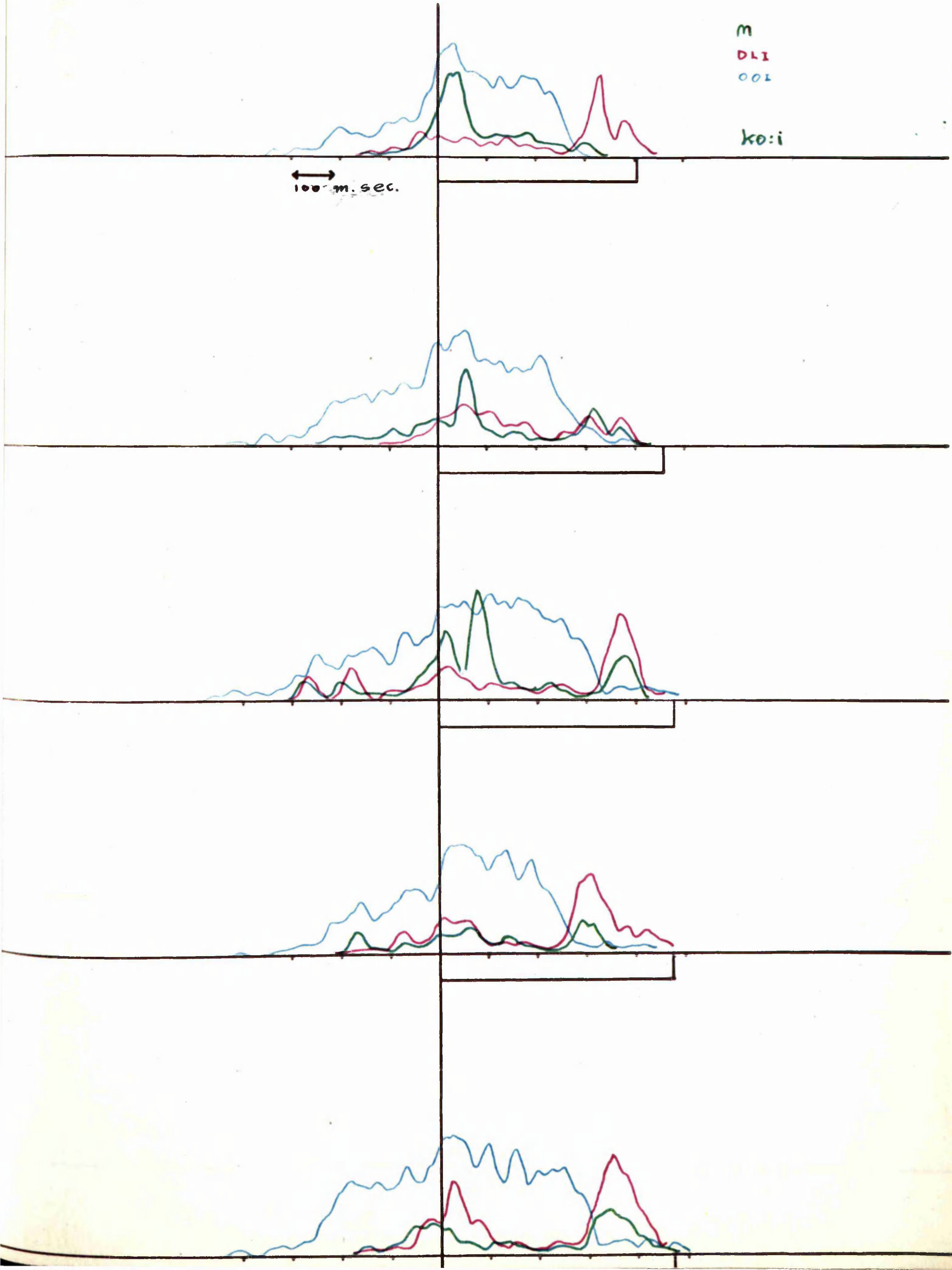


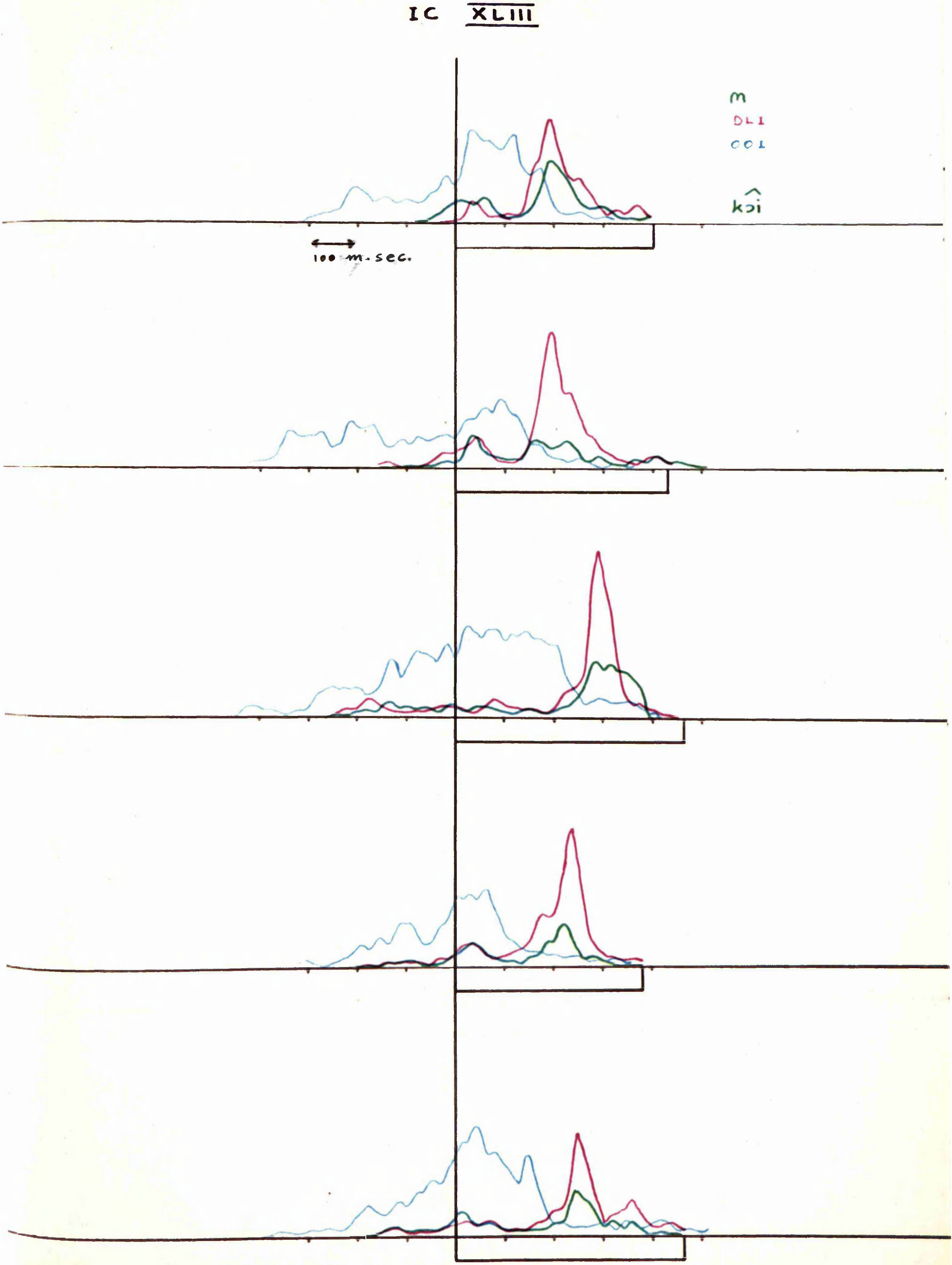

IC XL
m
DLI
OOI
Púa
100 m.sec.

IC XLI

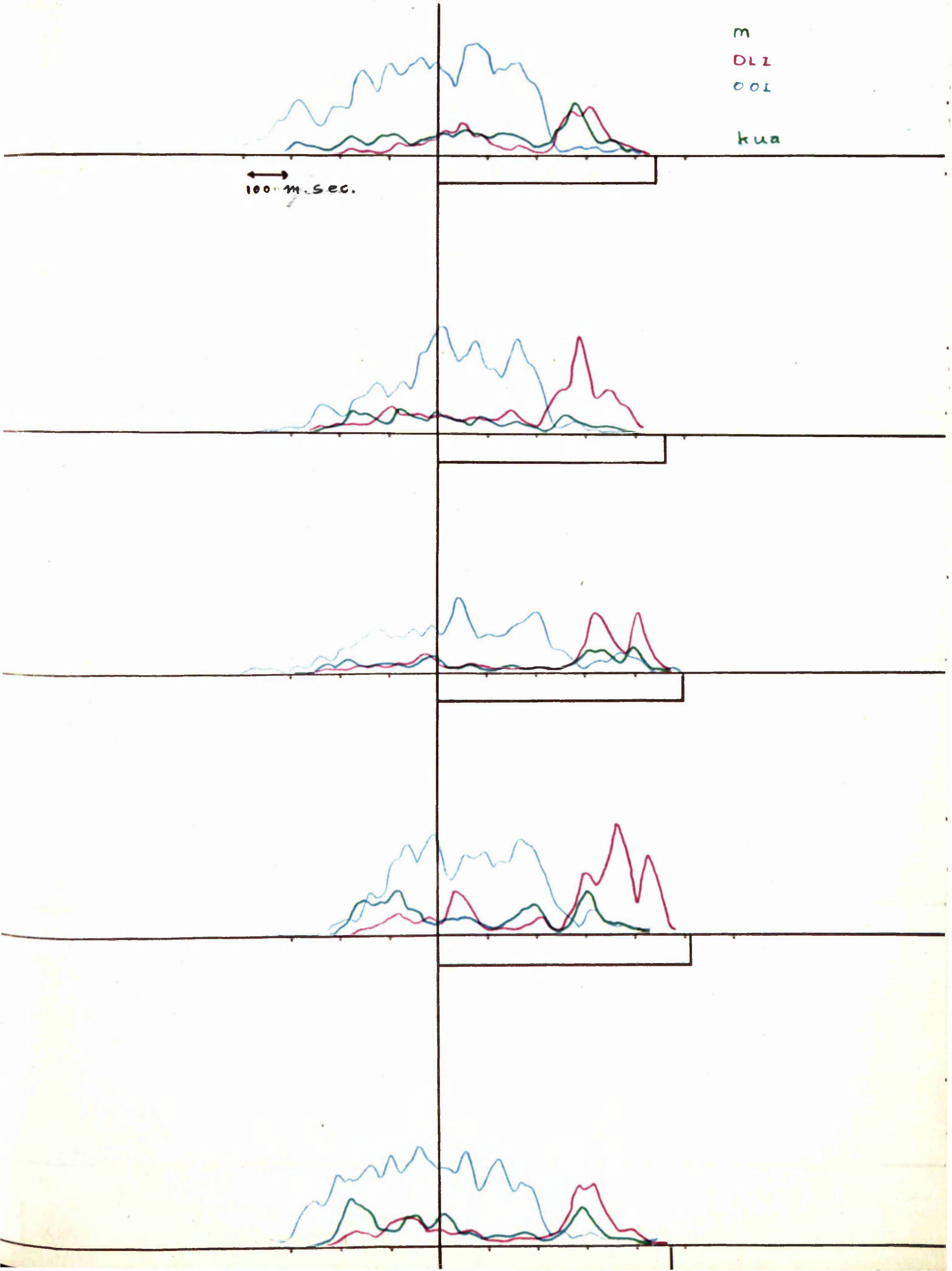


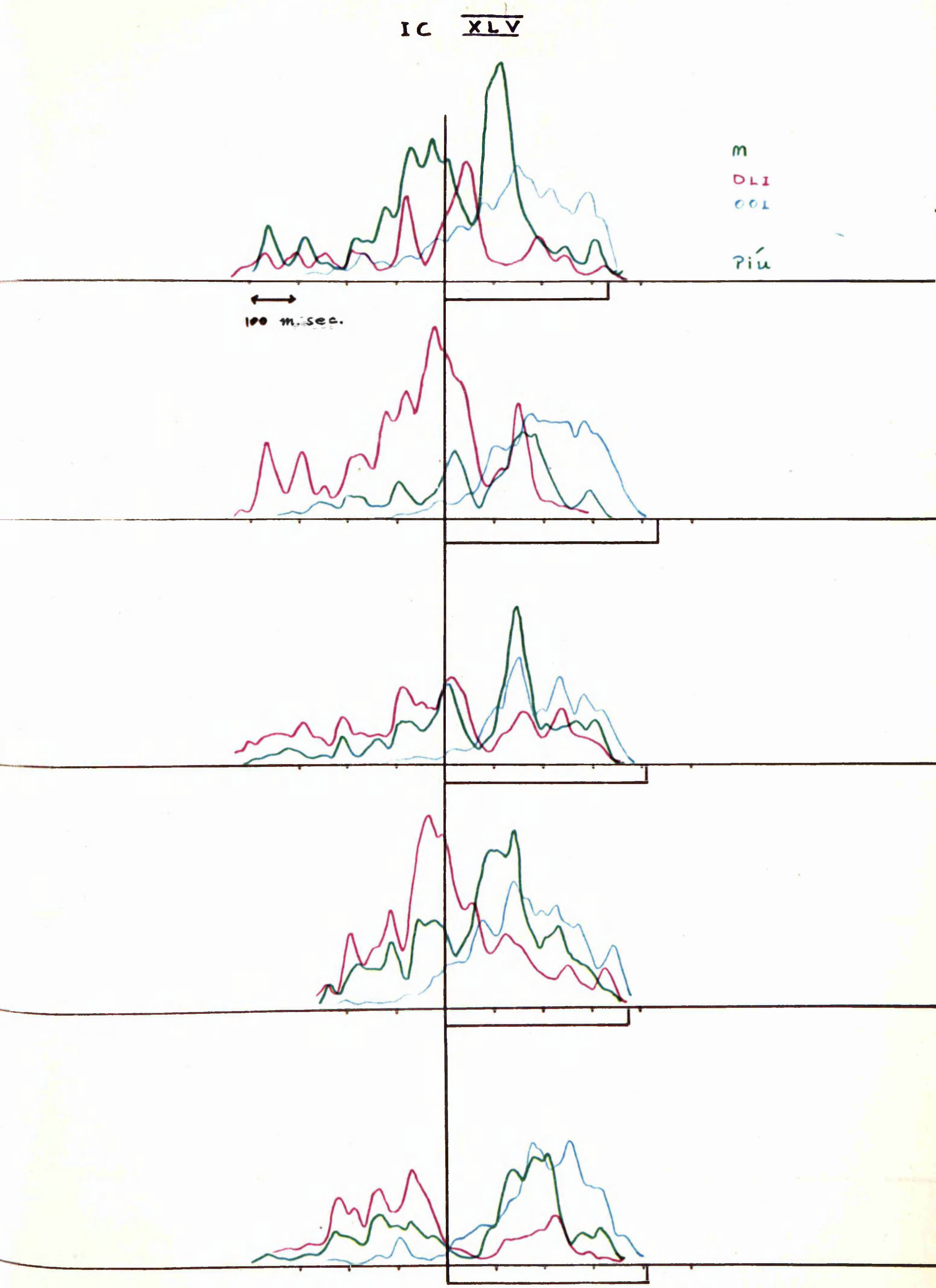
IC XLII



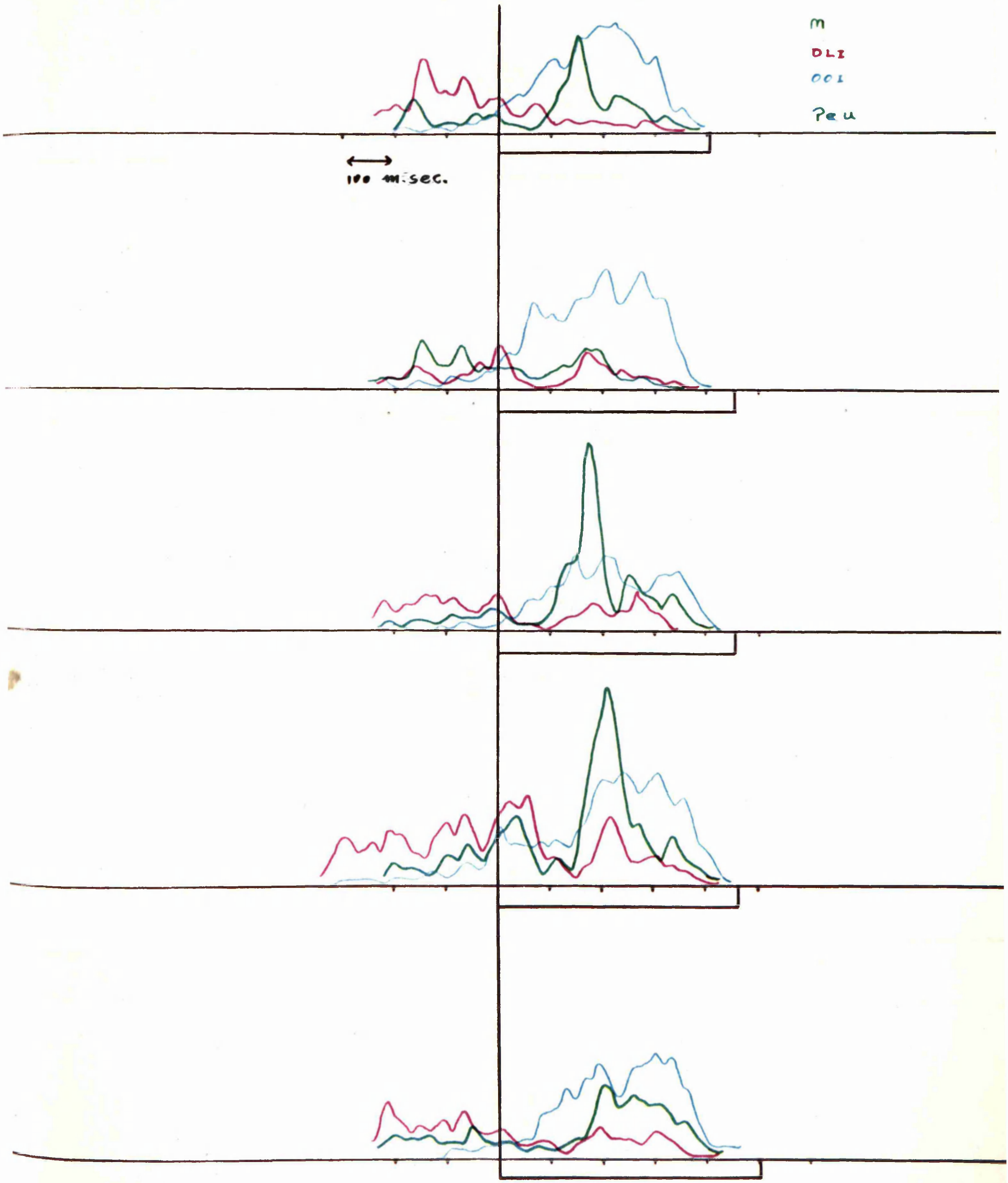

IC XLIII
m
DLI
COL
kɔ̂i
100 m.sec.

IC $\overline{\text{XLIV}}$

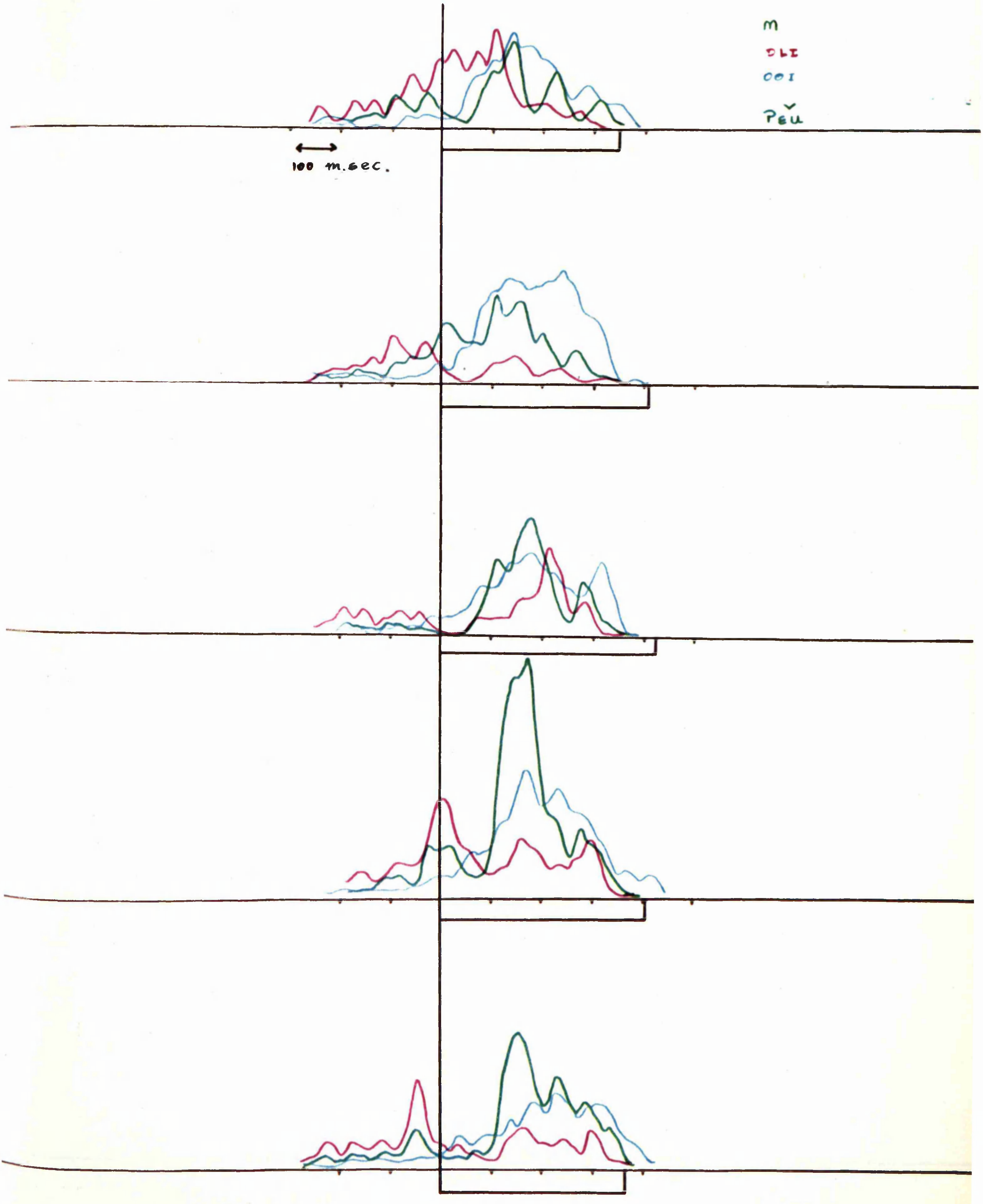



IC XLV
m
DLI
OOL
Piú
100 m.sec.

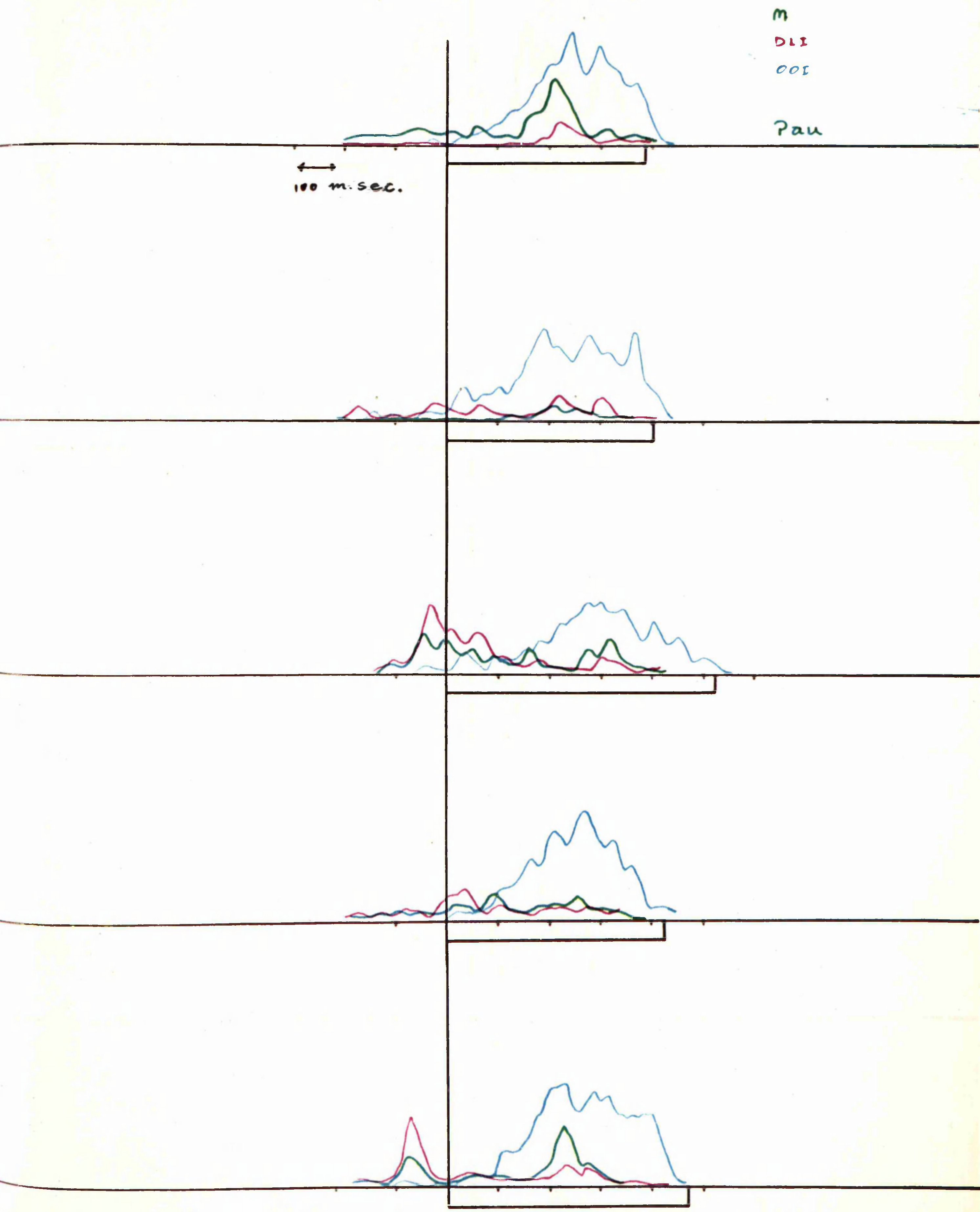
IC XLVI



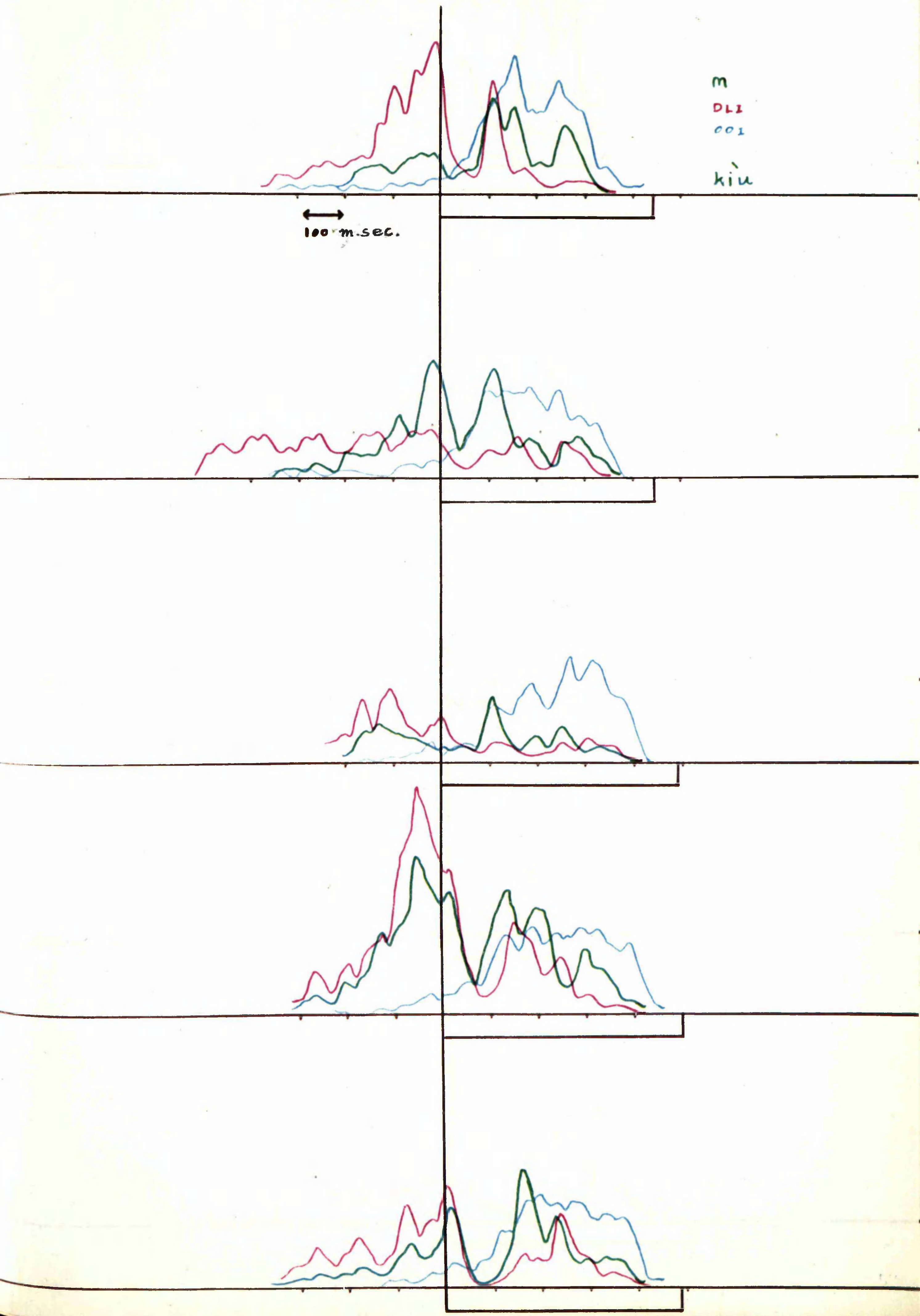
IC XLVII

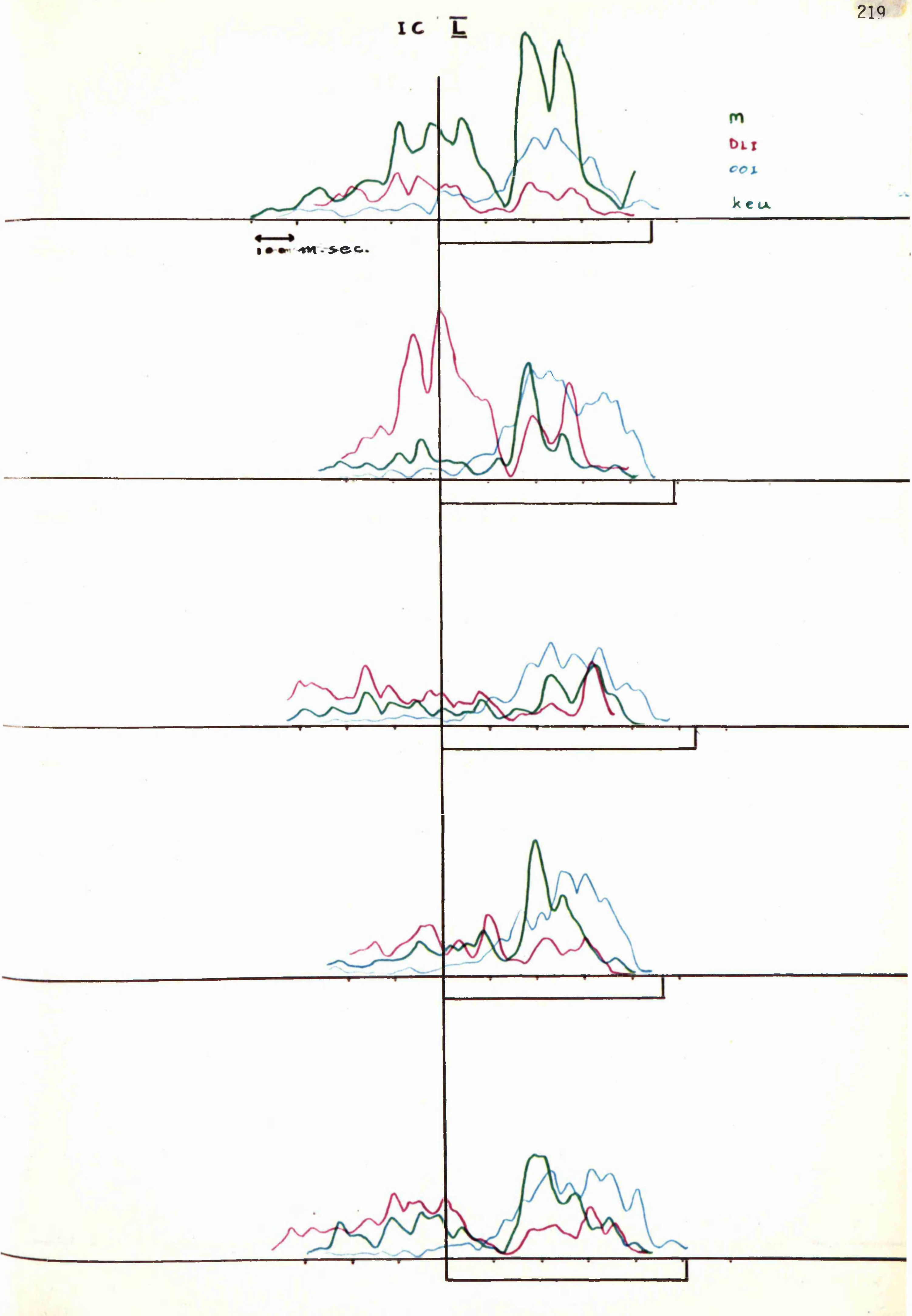


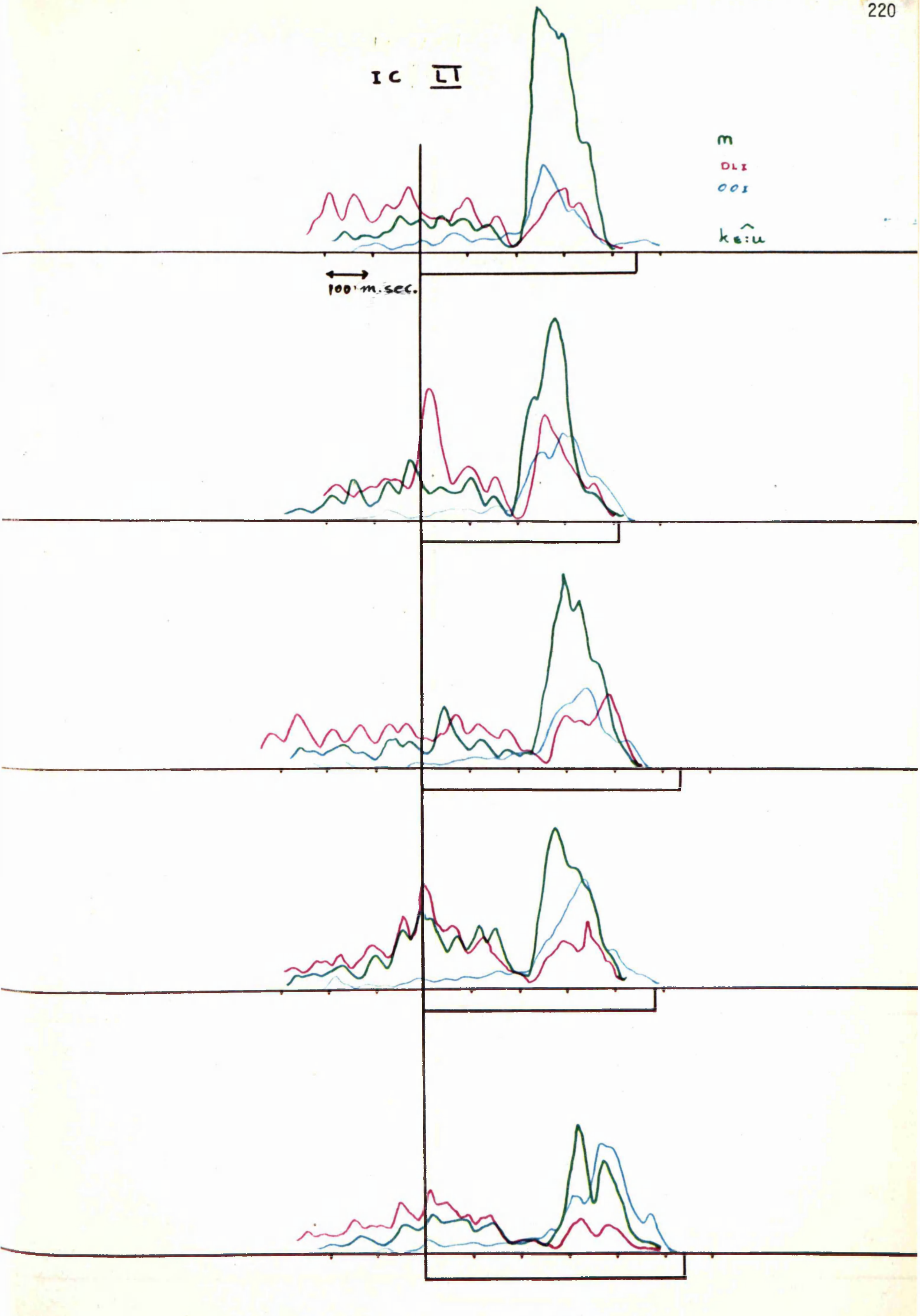
IC XLVIII



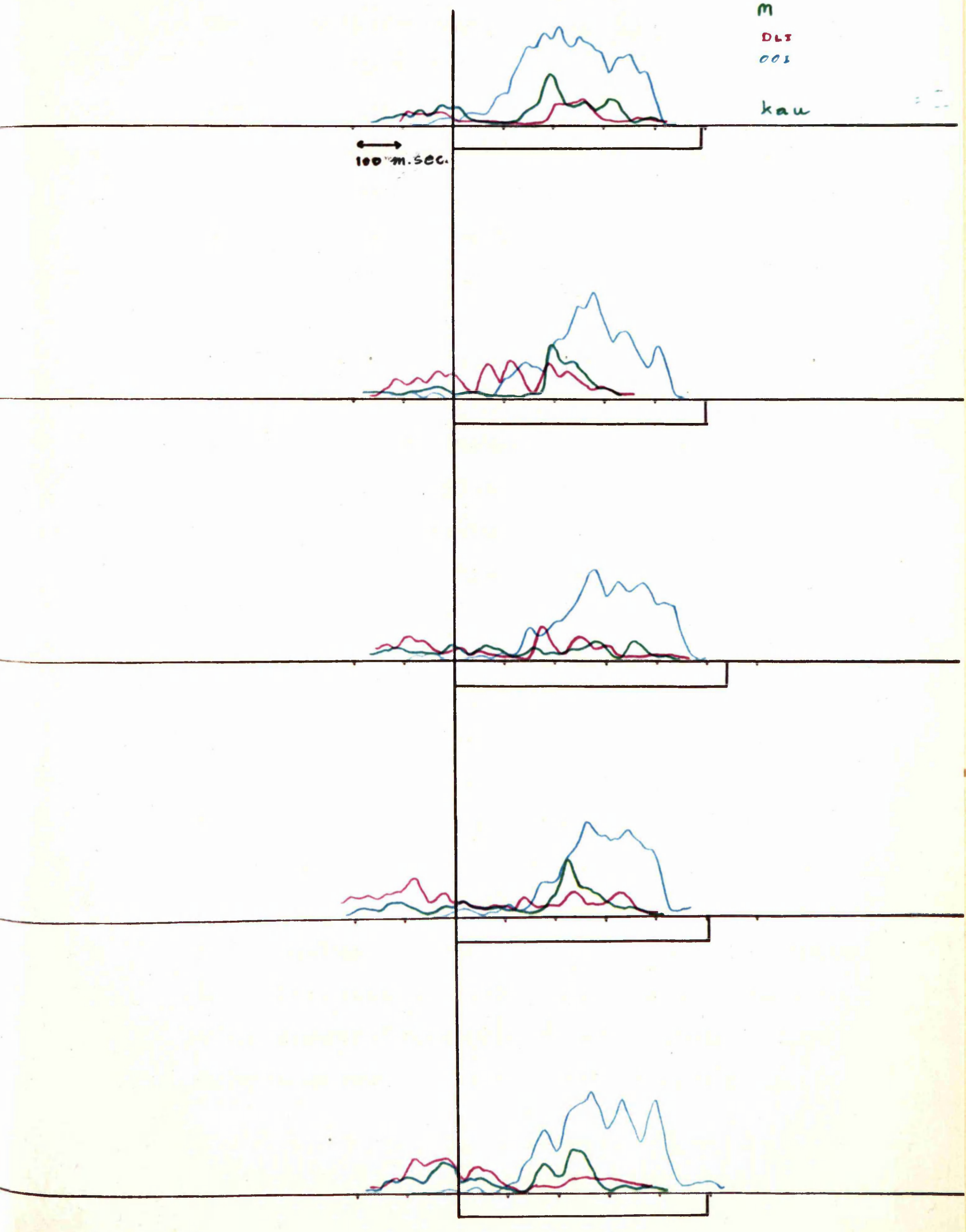
IC XLIX




IC L
m
DLI
OOI
keu
100 m.sec.


IC LT
m
DLI
OOI
kɛ:u
100 m.sec.

IC LII



Coordination in triphthongs, [uai, iau, wai]

(see IC LIII-LVIII)

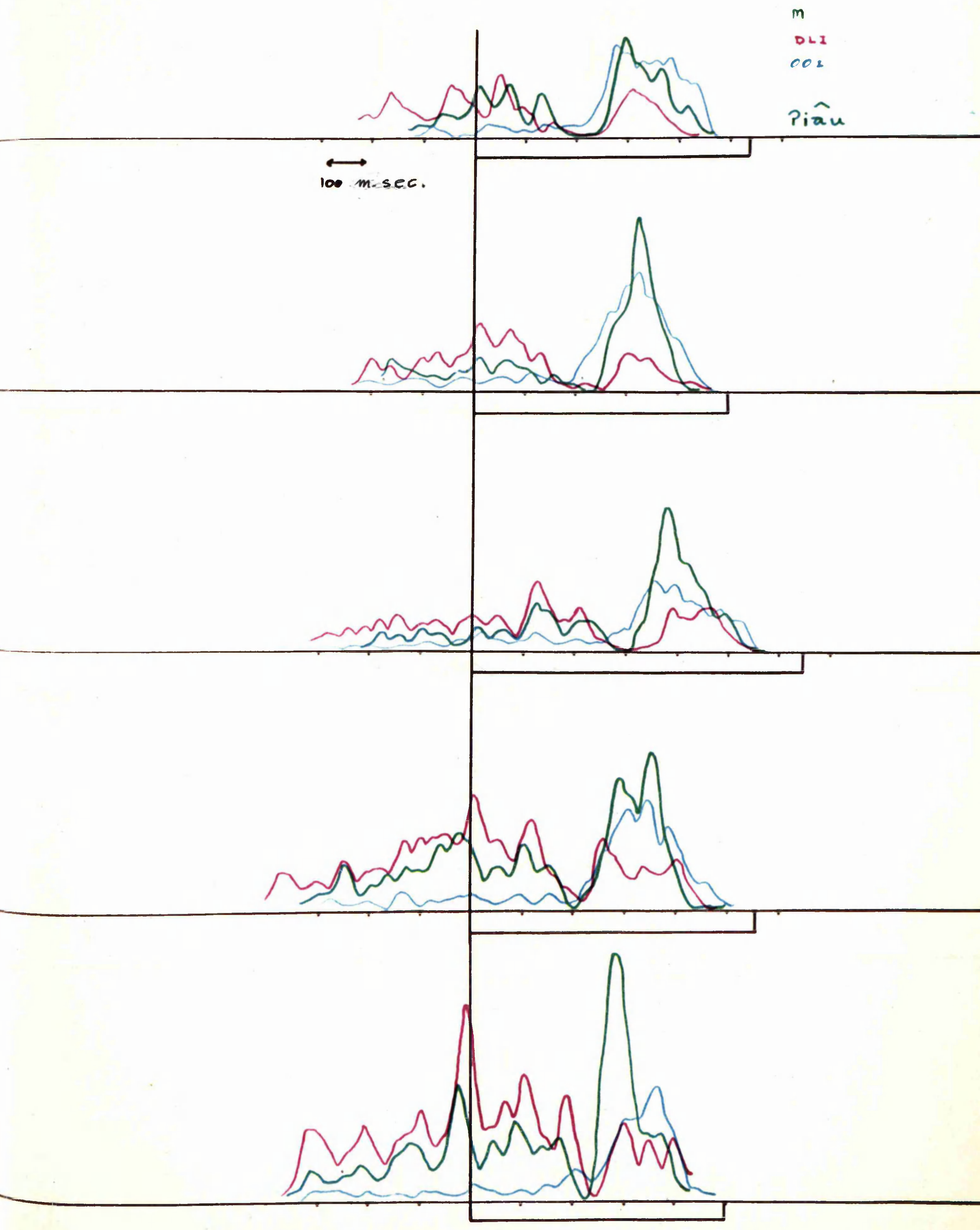
Comments on IC LIII-LVIII.

By comparing the integrated curves between the syllable preceded by [?] and those preceded by [k] it can be seen there was a distinction of muscular activity occurring. In [?uai] the DLI muscle seemed to behave, first, antagonistically with the mentalis, which was initially sharply activated, then the DLI activity dropped to the prespeech level while the OOI muscle was performing the rounding gesture. On the other hand, in [kuâi] the DLI did not have antagonistic action because the mentalis muscle was not initially activated as in [?uai]. Thus, in the syllable preceded by [k] there was only the prespeech activity which started early during the OOI activation.

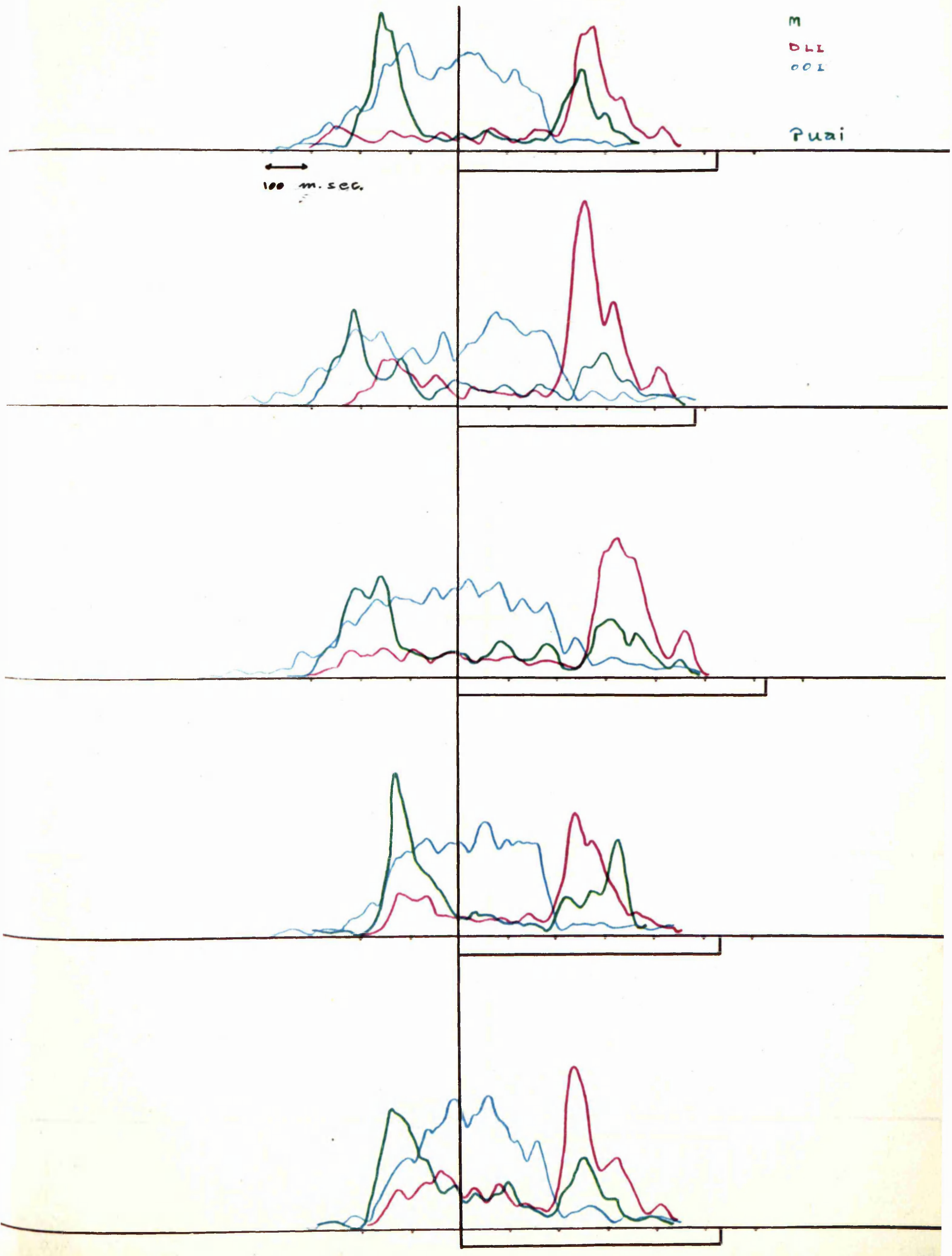
In [?îau] and [kîau] the pattern of muscular action potentials was relatively the same (see IC LIII and LVI). That is, there was an occurrence of the OOI prespeech activity during the DLI action. Then the mentalis muscle was strongly activated for the final rounding gesture. The mentalis activity was followed by antagonistic action from the DLI muscle. The evidence of muscular coordinative patterns seems to provide strong support for the hypothesis that the mentalis was acting as the initiator for an abrupt rounding. The DLI activity during the OOI action is also evidence of the antagonistic action potentials picked up during sudden rounding movements. Furthermore, in the [wai] the DLI prespeech potentials also started as early as the onset of acoustic activity. This event implies that the initial part of the syllable needs a neutral posture, otherwise there might have been DLI muscular activity occurring prior to the acoustic onset in order to prepare the oral configuration for the spreading element.

Apparently, from the dynamic point of view, the muscular coordination both in the diphthongs and the triphthongs overlaps along the time dimension.

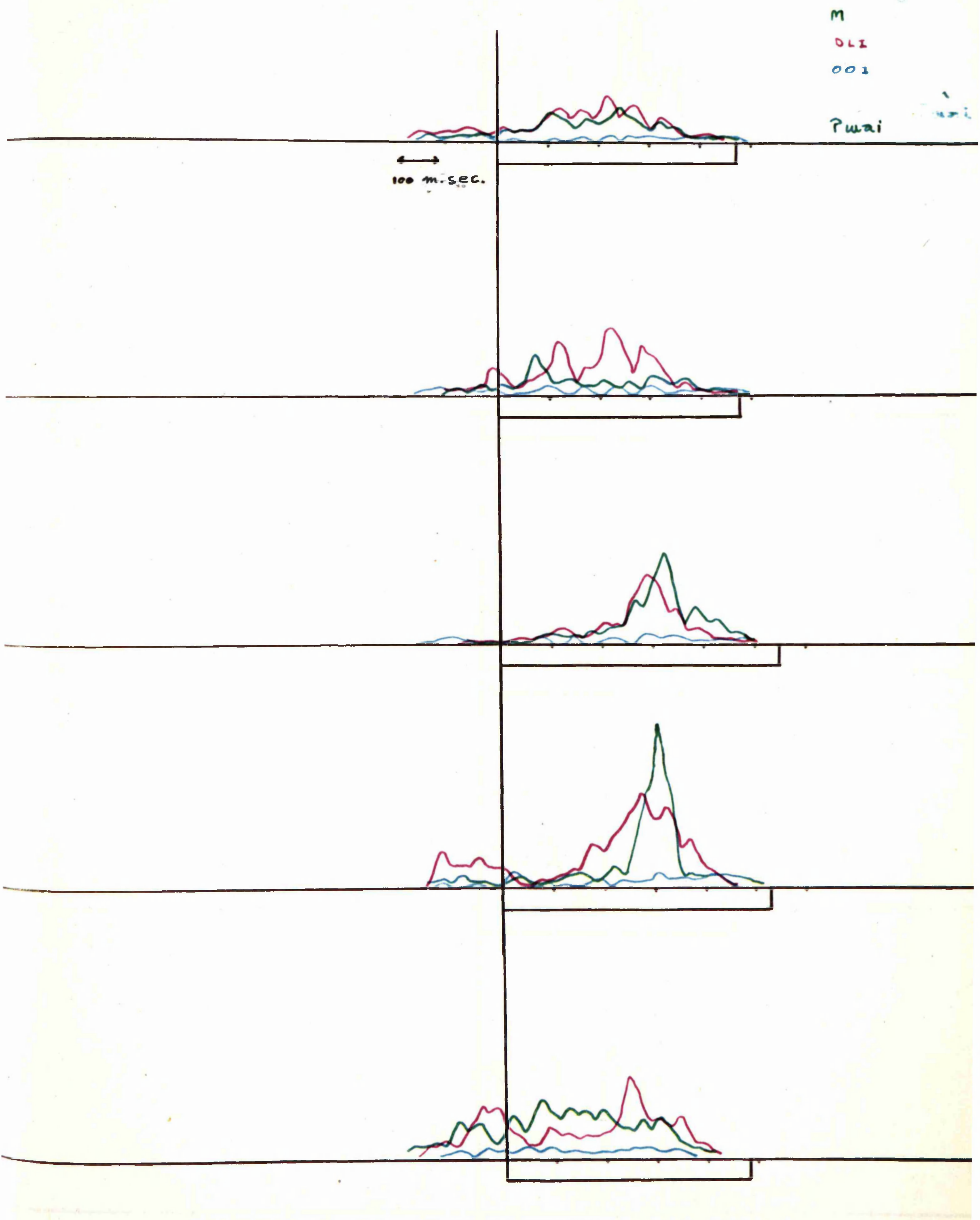
IC LIII



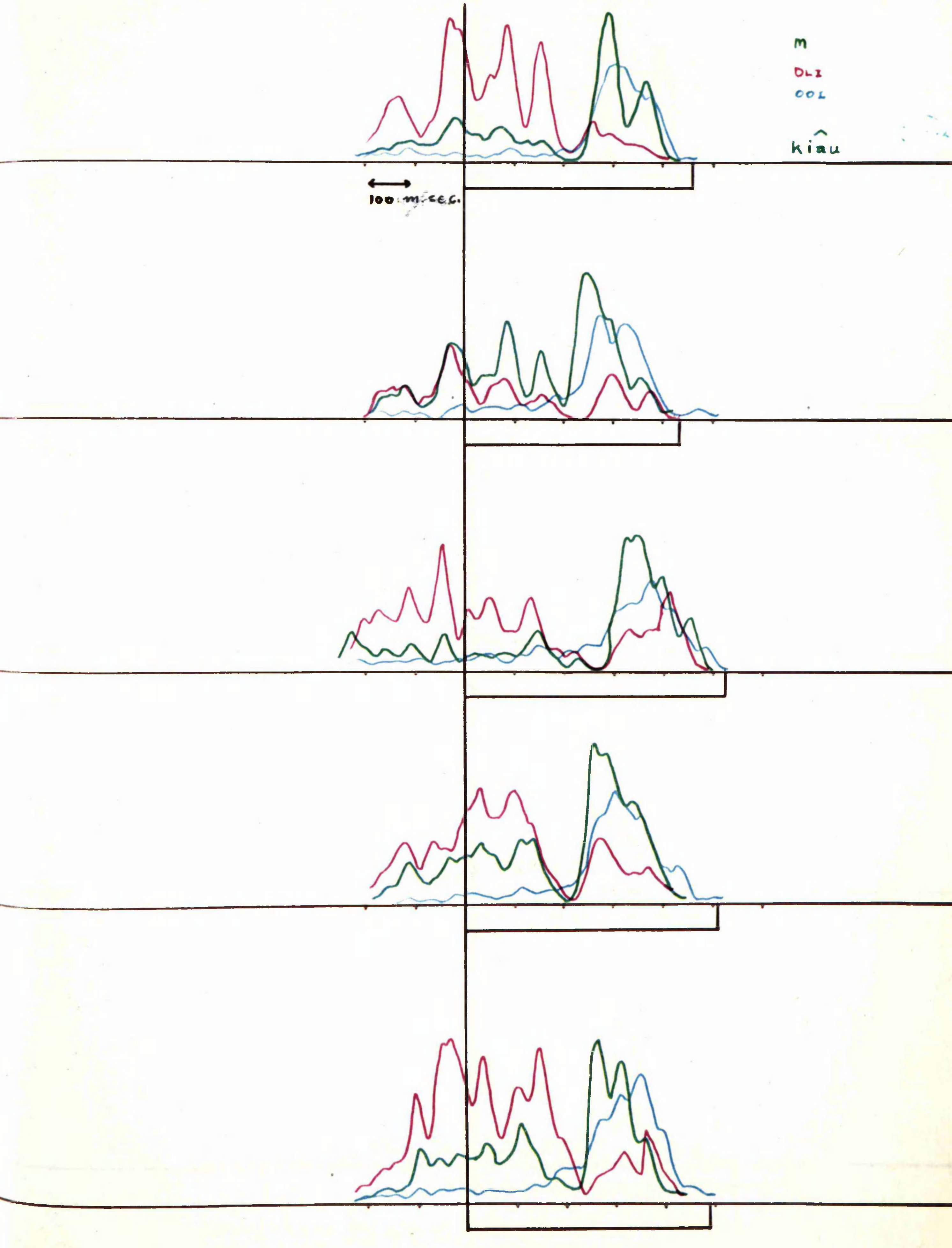
IC LIV



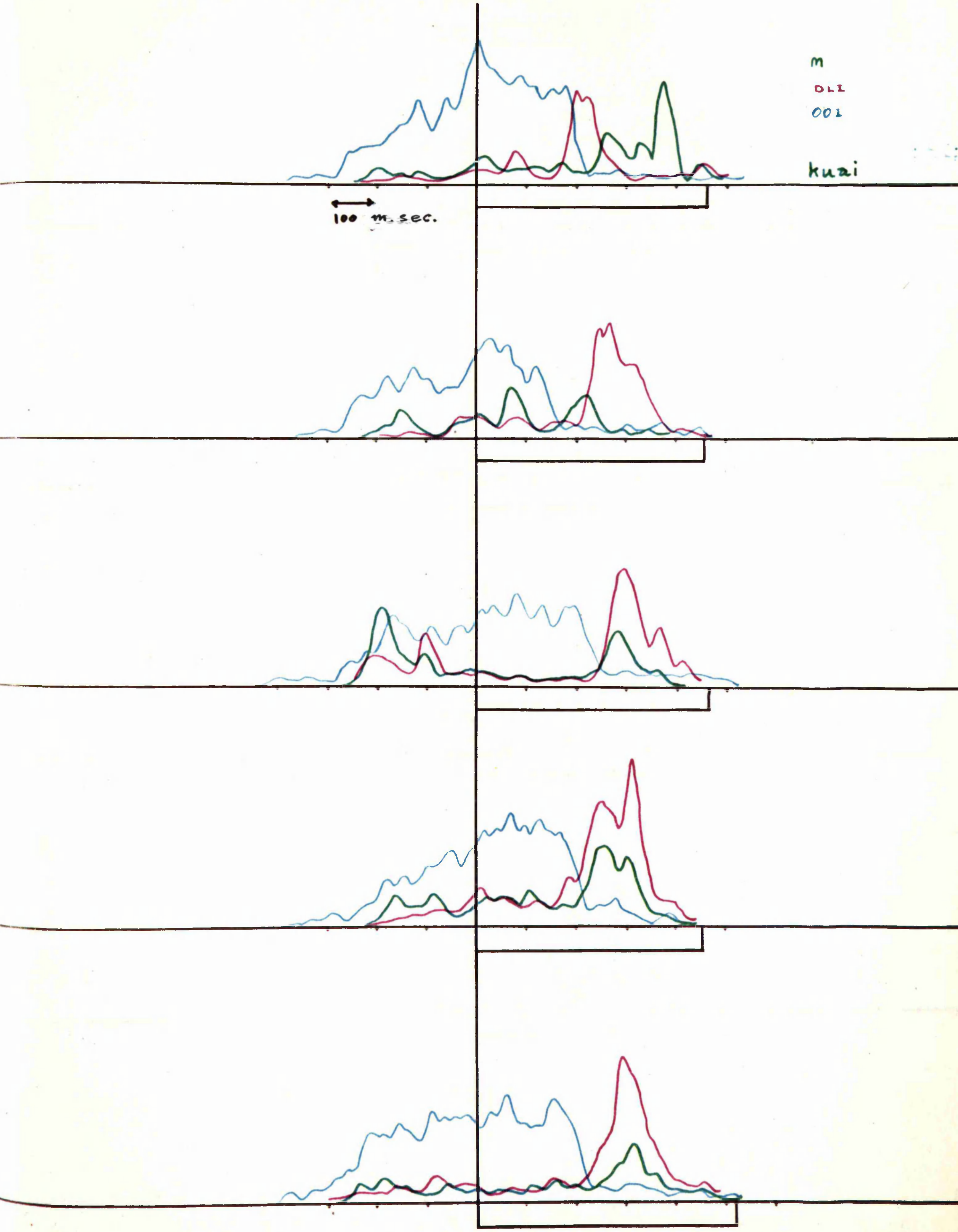
IC L V



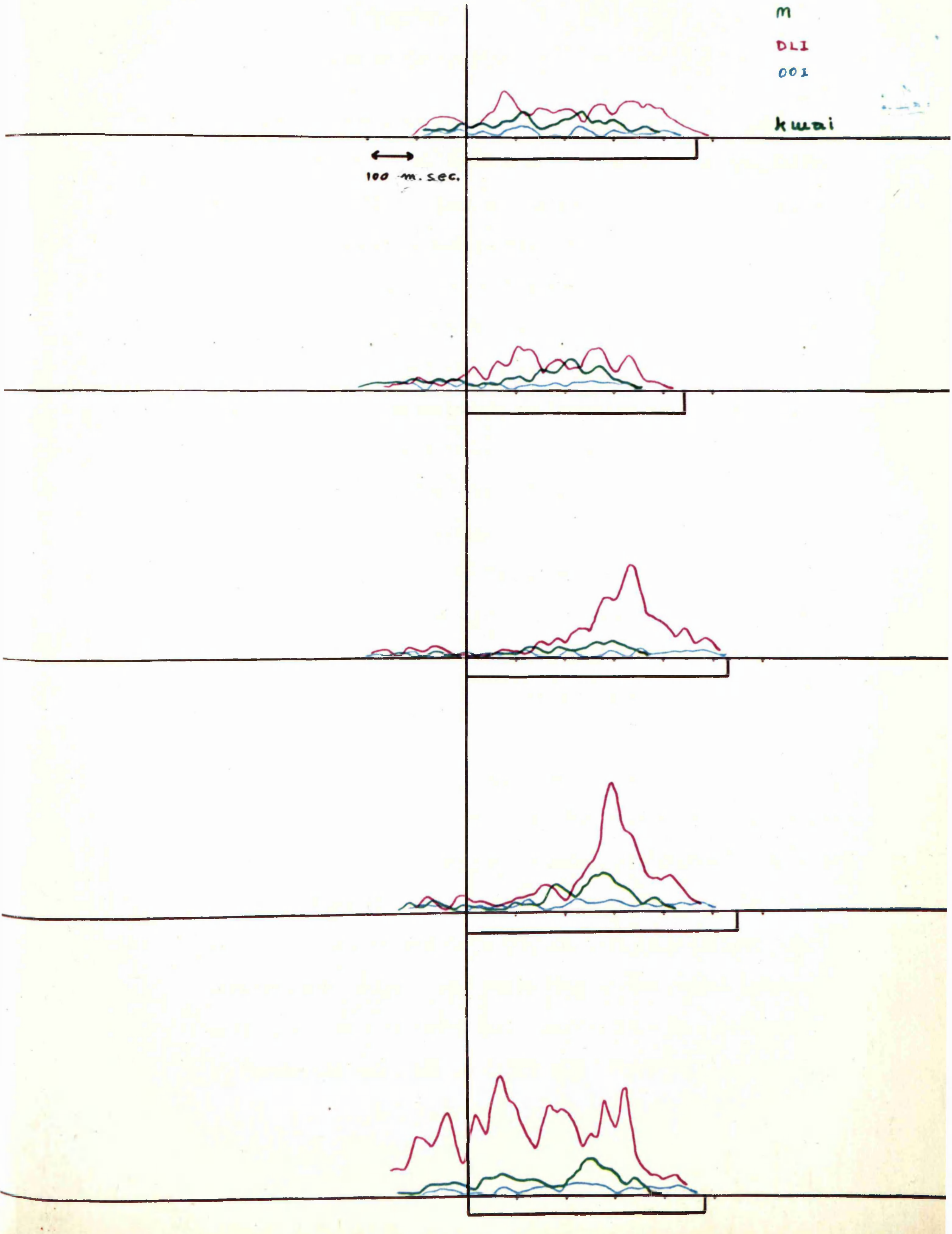
IC L VI



IC LVII



IC L[illegible]VIII



CHAPTER 9

GENERAL DISCUSSION

Peripheral motor command and phonological units.

The relation between motor commands and phonological units has been the subject of controversy. There has been considerable disagreement in the interpretation of results. From the Haskins Laboratory (Lieberman et al., 1964) it was reported that there appeared to be a common core of EMG activity that remained constant when a phoneme appeared in different contexts. This conclusion is in favour of the concept that a phonological element is correlated with a fixed pattern in the brain. The Haskins group claimed that the EMG correlates of the phoneme were invariant, in that the EMG studies of the lips and palate and of the facial musculature were initially interpreted as strongly supportive of the claim of invariance. However, a re-examination of these studies showed that their support for the concept of invariance is not as strong as it was at first thought to be.

Another group (Öhman, Persson, and Leanderson, 1967) concluded from their EMG investigation that there is a minimal neural unit corresponding to a phoneme, registered in the brain. In their view, it is the specification of the vocal-tract configuration required for a phoneme that is invariant, the occurrence of articulatory variations in the actual utterance being the result of contextual constraints. As also stated by Leanderson and Lindblom (1972:362) "There is clear evidence that the EMG activity is context-dependent. Vowel duration varied systematically as a function of both vowel identity and consonantal environment".

Fromkin (1968: 4), however, made an EMG investigation of the English bilabial consonants. She found that the EMG of the consonants in initial position differed from those in final position. She concluded from this that one must assume that there must be different sets of motor commands for at least some of the allophonic variants of phonemes, i.e. those called "extrinsic allophones" by Ladefoged (1966). Finally, Fromkin suggested two alternative interpretations of the fact that the neural muscular correlate of a given phoneme is different in different phonetic contexts (1968: 170).

"1. The minimal linguistic unit corresponding to the motor commands which produce speech is larger than the phoneme, perhaps more of the order of a syllable;

2. Motor commands related to phoneme production are altered, i.e. context restricted, either by feedback information concerning the existing state of muscular motion, or by stored information in the short-term memory."

The results of the present investigation seem to support the suggestion that the minimal unit of neural organisation is syllable-sized rather than segment-sized. The EMG evidence for the (CV) syllables containing monophthongs shows no one-to-one correspondence between C or V segments and neural commands. The rounding gesture for the vowels has anticipatory activity prior to the preceding consonant. This anticipation was found also in the vowel production of American English (Fromkin, 1968), Russian (Kozhevnikov and Chistovich, 1965), and Swedish (Leanderson, Persson, and Öhman, 1971; Lubker et al., 1974; Hadding 1969, 1976). Despite the primacy claimed for syllables of the structure CV (Jakobson, 1966), it is evident that the implied sequence of units C-V has no counterpart at the neuro-motor command level. Instead there is a dynamic event, which might more appropriately be schematized as $^{V}\overrightarrow{CV}$.

The EMG evidence from diphthongs and triphthongs seems also to support this hypothesis. The neural programming appears to be extended beyond any one element of a diphthong or of a triphthong. The evidence of muscular coordination suggests that a diphthongal or a triphthongal utterance is performed in response to a single motor command programme. This favours the phonological interpretation of Thai diphthongs and triphthongs as monophonematic units, rather than as sequences of phonemes, as is frequently done in Thai phonology in the name of 'economy' and 'simplicity'.* As Laver (1970: 73) said: "Articulation contraction is the result of a specific neural control program". The production of an acceptable utterance somehow seems to be controlled by self monitoring which is partially automatically constrained by acquisition from childhood. In other words, the range of target positions is a linguistic capability already established at the language acquisition stage.

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* For example, the diphthong [aɪ] is treated as a sequence of phonemes / a / and / y /.

Labial mechanisms and distinctive features.

The only features in the Chomsky and Halle system that could be correlated with the muscles investigated in this study are $\pm$ Round and Tense/Lax.

The Round/Spread distinction. The muscle principally associated with the feature +Round is OOI, though mentalis also plays a role. In general we can say that vowels classified as +Round will show presence of OOI activity, while vowels classified as -Round will show absence of OOI activity. The intensity dimension of OOI activity shows a gradient of degrees of rounding. Starting with the greatest degree of OOI activity and working down to the weakest, the vowels are: uː u, oː o, ɔː ɔ. This corresponds closely as one might expect to the degree of lip rounding which lessens as the vowels get more open. This could be specified by means of a multi-valued phonetic feature 'Round', with values ranging from 1 to 6.

Evidence from the EMG activity of the OOI and the mentalis indicates that the relationship between the distinctive feature +Round and the motor command for rounding gesture does not seem to be simple. In the syllables preceded by glottal stop the rounding activity of the labial parameter involves the initiating activity from the mentalis, while this activity seems to be unnecessary for the production of the rounding gesture of the syllables preceded by [k], (see IC XIII-XXIV).

The DLI is associated with spreading, for which there is no classificatory feature in the Chomsky and Halle system.

The vowels showing presence of DLI activity are: ɪ: ɪ, e:, e, ɛ: ɛ, a: a. The DLI intensity demension results in the following arrangement of vowels: i:, e:, ɛ:, ɪ , e , ɛ , (for a:, a see under Tense/Lax). The vowels ɯ:, ɯ , ɤ:, ɤ are characterised by absence of activity of OOI, DLI, and Ment. According to the lip muscles engaged in their production, the Thai vowels could be classified as below:

+Round	+Spread	-Round, -Spread
u:, u , o:, o , ɔ:, ɔ	ɪ:, ɪ , e:, e , ɛ:, ɛ	ɯ:, ɯ , ɤ:, ɤ
	a:, a	

This classification corresponds quite well to the traditional classification in terms of tongue height, part of tongue raised, and action of the lips, though it might perhaps have been expected that [a:, a] would belong to the -Round, -Spread group.

The Tense/Lax distinction. Tenseness is defined by Jakobson, Fant and Halle (1967: 36) as follows "In terms of production: tense phonemes are articulated with greater distinctness and pressure than the corresponding lax phonemes... The higher tension is associated with a greater deformation of the entire vocal tract from its neural position. This is in agreement with the fact that tense phonemes have a longer duration than their lax counterparts". By Fant (1972: 363) the feature was defined "Tenseness is phonetically described by an articulation with greater overpressure behind the place of the active sources in the case of vowels a higher subglottal pressure... tenseness is associated with a more extreme articulatory position... the longer duration and high intensity of the noise". According to the Chomsky and Halle distinctive features parameter, tense and lax in vowels seem to be the redundant features of long and short.

In investigating degrees of tenseness in vowels it would clearly be of prime importance to investigate the tension of the tongue muscles. It may be interesting, nevertheless, to look at the Thai vowels from the point of view of the tension of the lip muscles.

Judging by the intensity dimension of EMG of the labial muscles, there is no correspondence in Thai between a long vowel and high muscular tension, or a short vowel and low muscular tension. In the round vowels the EMG intensity dimension correlates, as we have seen above, with the degree of lip rounding. That is, we have round with high muscular tension, clearly indicated by plateau-like curve and round with low muscular tension, indicated by pyramid-like curve (see AIC I, II, III). This is of course at variance the Chomsky and Halle model, which treats tense/lax as co-terminous with long/short, and would produce a cross classification:

+Tense	-Tense(Lax)
u:	u
o:	o
ɔ:	ɔ

An implication for the traditional classification may be that short vowels are "lax " relative to " long " tense counterparts, interpreted literally with respect to the underlying muscle activity patterns. This implication requires greater activity in all the relevant muscles for the tense vowel. However, according to Raphael (1971), Raphael and Bell-Berti (1975) have shown that there is no evidence in English.

Looking at the intensity dimension of DLI activity we find a picture that corresponds fairly closely to the traditional feature classification, i.e. [i: e: ɛ:] would be +Tense, [i e ɛ] -Tense (Lax).

Moreover, regarding the DLI activity in [a: a] (see IC XXV), although there was a sign of muscle activation, no muscular distinction between the two can be observed. These vowels, therefore, have to be classified as lax for both the long and the short counterparts.

It is also evident from the EMG traces of the OOI, the DLI, and the mentalis that there is hardly any muscular activity producing the back unrounded vowels [ɯ: ɯ ɤ: ɤ]. The lips seem to be in neutral posture while producing the vowels. From an articulatory point of view, therefore, this characteristic physiologically indicated that the nonlabial activity is a feature differentiating the [ɯ: ɯ ɤ: ɤ] from other monophthongs. Judged from the point of view of the tension or lack of tension of the lip muscles, these vowels would also have to be classed as -Tense (Lax).

A proposed chart.

The following rearrangement of the Thai vowels in terms of muscular tension of the lip parameter is presented:

Spread		Neutral	Rounded	
tense	lax	lax	tense	lax
i:	i	ɯ:	u:	o
e:	e	ɯ	u	ɔ:
ɛ:	ɛ	ɤ:	o:	ɔ
	a:	ɤ		
	a			

The above arrangement reflects Henderson's comment (1975: 261) "That so many writers have labelled [ɯ] ,[ɤ] as central, along with [a] , does not, of course, necessarily mean that they believed them to be central in tongue position. More probably the writers in question were not much concerned with phonetic detail, and chose 'central' as a convenient lable for vowels which are neither the familiar front unrounded nor back rounded, but something 'between'the two' in some sense, i.e. spread like a front vowel, but more retracted, like a back one".

It is recognised that the present study is only a preliminary investigation based on only three major lip muscles involved in the articulation of vowels. Before any serious reapparaisal of Thai phonetics and phonology can be attempted, much more work is needed, on the other muscles involved in speech, especially those of the tongue, and on many more consonant and vowels combinations.

It is hoped, however, that this first modest step encourages further electromyographic research into Thai, so as to provide not only precise specifications of physiological parameters but also to supply a sound basis for the establishment of the elements of Thai phonology.

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